NAVAL POSTGRADUATE SCHOOL
Monterey, California

THESIS

MODELING THE EFFECTS OF LOGISTICS ON GROUND COMBAT AND MANEUVER

by

Joseph W Huffaker

September 1996

Thesis Advisor: Arnold H Buss

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REPORT DOCUMENTATION PAGE

Form Approved OMB No. 0704

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instruction, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188) Washington DC 20503.

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE September 1996	3. REPORT TYPE AND DATES COVERED Master's Thesis

4. TITLE AND SUBTITLE
MODELING THE EFFECTS OF LOGISTICS ON GROUND COMBAT AND MANEUVER

5. FUNDING NUMBERS

6. AUTHOR(S) Joseph W Huffaker

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Naval Postgraduate School
Monterey CA 93943-5000

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
The views expressed in this thesis are those of the author and do not reflect the official policy or position of the Department of Defense or the U.S. Government.

12a. DISTRIBUTION/AVAILABILITY STATEMENT
Approved for public release; distribution is unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT (maximum 200 words) Logistics can substantially affect the directions of warfare campaigns. The types of war materiel and their flow rates to field units directly impact the campaign outcome. Although many wargaming and combat simulations have been developed, few models implement the detailed effects of logistics flow. This thesis develops a theater level logistics flow model for a Blue force using a forward logistics base that is advancing upon an objective in Red defended territory. The model computes confidence intervals for Blue's short tons of various classes of supply available throughout the campaign. Logistics activity is generated at user defined rates using four periodic and event driven consumption mechanisms: movement, combat, interdiction, and interdiction repair. The model's primary function is receipt, staging, onward movement, and integration for materiel consumed by Blue. The model is implemented in MODSIM, an object-oriented simulation language providing both synchronous and asynchronous events, as well as a rich class of data structures necessary to implement the model. The basic model is replicated to desired confidence and tolerance, with statistics collected for the amounts of the various classes of supply available for the supported units. The model's output includes confidence intervals for the desired measures of effectiveness

14. SUBJECT TERMS
Logistics, Combat Modeling, Logistics Modeling, Simulation

15. NUMBER OF PAGES
100

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)
Prescribed by ANSI Std. 239-18

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MODELING THE EFFECTS OF LOGISTICS ON GROUND COMBAT AND MANEUVER

Joseph W Huffaker
Lieutenant, United States Navy
B.A. Mechanical Engineering, United States Naval Academy, 1989

Submitted in partial fulfillment
of the requirements for the degree of

MASTER OF SCIENCE IN OPERATIONS RESEARCH

from the

NAVAL POSTGRADUATE SCHOOL
September 1996

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ABSTRACT

Logistics can substantially affect the directions of warfare campaigns. The types of war materiel and their flow rates to field units directly impact the campaign outcome. Although many wargaming and combat simulations have been developed, few models implement the detailed effects of logistics flow. This thesis develops a theater level logistics flow model for a Blue force using a forward logistics base that is advancing upon an objective in Red defended territory. The model computes confidence intervals for Blue's short tons of various classes of supply available throughout the campaign. Logistics activity is generated at user defined rates using four periodic and event driven consumption mechanisms: movement, combat, interdiction, and interdiction repair. The model's primary function is receipt, staging, onward movement, and integration for materiel consumed by Blue. The model is implemented in MODSIM, an object-oriented simulation language providing both synchronous and asynchronous events, as well as a rich class of data structures necessary to implement the model. The basic model is replicated to desired confidence and tolerance, with statistics collected for the amounts of the various classes of supply available for the supported units. The model's output includes confidence intervals for the desired measures of effectiveness.

THESIS DISCLAIMER

The reader is cautioned that computer programs developed in this research may not have been exercised for all cases of interest. While every effort has been made, within the time available, to ensure that the programs are free of computational and logical errors, they cannot be considered validated. Any application of these programs without additional verification is at the risk of the user.

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EXECUTIVE SUMMARY

Logistics can substantially affect the course of a military campaign. The types of war materiel and their flow rates to field units directly impact the campaign outcome. At the same time, military planners have fewer tools available to them to investigate the effects that logistics might have on a developmental plan than they do tools to help them shape the combat aspects of that plan.

Campaign issues are often evaluated using established combat models like TACWAR, RESA, and JTLS. Combined with live exercises and wargames, they can provide significant insights to faults in the plan and to the comparative strengths and weaknesses of competing courses of action. Some of these combat models do have extensive logistics modules that track materiel expenditure; however, they have difficulty analyzing future logistics requirements.

This thesis develops a logistics flow model to fill this gap in investigating the future effects of logistics on ground maneuver and combat arising from a general lack of logistics planning aids in modern combat models. The proposed model is an object-oriented modular approach that allows it to grow and develop easily to meet future needs and refinements.

The basic purpose of the model is to provide confidence intervals for the amounts of war materiel supported units might have as the campaign progresses. Logistics consumption mechanisms like movement, combat, interdiction, and interdiction repair spur the logistics flow from a forward logistics base to the supported units. The progress of these units in reaching their objective is directly related to their logistics sustainability. Two measures of effectiveness, days of supply and events of supply, are used to measure sustainability. The goal of these confidence intervals and measures of effectiveness is to give military planners insight into the logistics feasibility of various courses of action over an extended period, complementing the ability of current combat models that report the current logistics situation.

Demonstrations showcase different functional areas of the model and show that the ground campaign suffers when the logistics lines of communication are stressed.

I. INTRODUCTION

A. SCENARIO

A US ground commander is tasked to develop a campaign plan in the event that hostilities start in his theater. His particular campaign will be a part of the larger overall war plan; fulfilling this particular campaign objective is critical to the overall success of the war.

The Korean Peninsula provides such a case in point. Should hostilities in the Korean theater, in a state of armistice since July 1953, resume, then plans in current development, review, and implementation will be put into action.

B. DISCUSSION

The commander developing a campaign has many combat models available for investigating various courses of action. Tactical Warfare (TACWAR), Research, Evaluation, Simulation, and Analysis (RESA), and Joint Theater Level Simulation (JTLS) are several that the US military presently uses.

Often, campaign issues are also studied by combining live wargames and exercises with combat model analyses in an effort to get more of the "man in the loop" viewpoint and to exercise the plan to find its limits. Ulchi-Focus Lens (UFL) is an annual exercise in South Korea that does just this. As a result, a plan has been examined from many aspects of military perspective by the time it is mature. At the same time, logistics planning for the campaign may be less well developed for several reasons:

1. Most exercises are considerably shorter than the anticipated war. Accordingly, calculating the effects of logistics on the campaign over the long term requires more simulation and imagination than watching Marines spill ashore over several days.

2. Although established combat modeling systems, like TACWAR, RESA, and JTLS, have integrated logistics modules, these modules are an adjunct to the combat focus of the system. For example, JTLS will restrict the player from launching a missile raid if the firing units do not have any missiles, or in fact, from performing any activity for which there are not enough supplies. The player must create and execute a (logistics) resupply plan and launch the raid later. While this may allow military planners to identify potential logistics shortfalls and bottlenecks, it requires staffs to play the war game for an extended period just to see the logistics picture for one course of action.

3. The accuracy of long term logistics forecasting degrades substantially as the timeline is played out. Also, logistics usage depends heavily on the events which unfold in the scenario. Trying to integrate any forecast to the vagaries of war, or a war plan, magnifies the complexity of accurate forecasts.

Military planners have few tools available for logistics planning due to the difficulties involved. At the same time, command and control systems like JOPES (Joint Operational Planning and Execution System) and WMCCS (World Wide Military Command and Control System) use logistics patterns as an integral part of an operations plan. For instance, the Time Phased Force Deployment Data (TPFDD) schedules unit and materiel flow into the theater as the war unfolds. Ideally, effective staff work moves units and materiel at compatible rates so that situations in which several divisions are available to fight, but have no ammunition, or depots are full of ammunition and have no customers, develop. Military staffs entering the TPFDD may have to resort to best guesses about how much materiel to flow and when to move it without either good data or good modeling tools.

In spite of these planning difficulties, the needs of logistics in conflict do not wait for planning, as the US experience in Operations Desert Shield/Desert Storm (DS/DS) demonstrated. General Pagonis, the commanding general for logistics in DS/DS, wrote of his experience in August, 1990 of watching nearly every logistician in the theater try to process plane load after plane load of the arriving 82nd Airborne [Ref 1: p. 85]. He summarized the vast quantities of materiel that the US used and moved, writing:

> ...In the year between August 1990 and August 1991...the logisticians...planned, moved, and served more than 122 million meals. This can be compared to feeding all of the residents of Wyoming and Vermont three meals a day for forty days.
>
> ...Between August 1990 and August 1991, those same supply units pumped 1.3 billion gallons of fuel...roughly equal to the 12-month fuel consumption of the District of Columbia, Montana, and North Dakota combined.
>
> ...those supply units and their contracted drivers drove almost 52 million miles in the war theater. This is the equivalent of more than 100 round-trips to the moon. [Ref 1: p. 1]

Another aspect of DS/DS that worked well for US forces was the establishment of Forward Logistics Bases (FLB). It is likely, then, that having worked well in DS/DS, they will be used again in the future.

The FLB can be a tent city erected in the desert, a city near the front, or existing infrastructures improved to meet the needs of the conflict. Key characteristics are proximity to intermodal infrastructures such as seaports, airfields, railheads, and highways. Other useful intermodal infrastructures include canals, rivers, and beaches suitable for operations like Joint Logistics Over the Shore (JLOTS). The FLB and the intermodal infrastructures between the bases and the troops must also be able to support the troop's style of warfare. Forces advancing rapidly, hoping to maneuver past opposition before reaching the objective, might experience rapidly elongating lines of communication susceptible to interdiction.

C. COMPLEMENTING COMBAT MODELS

The flow of logistics can either help or hinder a campaign, and therefore the war. The campaign plan, then, needs effective logistics planning. A campaign is developed through the process of comparing different courses of action. The differing feasibilites of these courses distinguish stronger plans from weaker ones, as well as giving insights to the multitude of ways the plan might disintegrate when it comes in contact with the enemy for the first time. Ideally, logistics planning is an integral part of development, rather than a follow-on process to the campaign planning, for the same reasons.

A useful tool to integrated development would be a model that anticipates future logistics requirements so that planners can create more proactive logistics plans. Such a model would become a step beyond using the logistics modules contained in current combat models, where the model facilitates planning with comparative courses of action analyzed from a logistics perspective. The model would show insights to important questions, such as how much materiel might the supported units have well into the campaign, and whether or not the logistics flow help or hurt the advance.

This thesis proposes such a model. The proposed model bases logistics flow from a FLB at the theater entrance and uses logistics planning factors tied to friendly Blue and unfriendly Red activity to simulate the campaign from a logistics point of view. The resulting model complements and extends the focus of current combat modeling efforts.

II. METHODOLOGY

This chapter develops the framework for the model. The following chapters describe the logistics flow model and how the model is executed in MODSIM II.

A. THE PURPOSE OF THE MODEL

This thesis offers a logistics flow model that simulates the effects of logistics on ground combat and maneuver with the goal of giving military planners indicators for the levels of logistics support a FLB can give and for the effects of the intermodal infrastructures on that flow. These indicators are measured by how much materiel Blue has at the front throughout the campaign.

B. MODEL METHODOLOGY

The model is network flow based; nodes, demands, and arcs represent elements of infrastructure and lines of communication (LOC). Materiel moves from the FLB to the front using this network each time the model is used for a given scenario. Each scenario is defined by a set of user inputs.

User inputs to the model are databases detailing the forces, including their logistics and weapons loadouts, cartography, combat modeling factors like attrition rates and force allocations, and a depot based supply system. Logistics enter the theater through the FLB. Probabilistic elements are used to create meaningful differences between successive runs of a single course of action. Running a series of scenarios through the model builds the different courses of actions for comparative analysis yielding insights to the logistics portion of the campaign plan.

Each time the model is run for the simulation, series of instantaneous looks at stock levels are taken. These snapshots from a single run portray the logistics flow in the campaign. The corresponding snapshots from a series of runs show a range of possible outcomes. These snapshots are like a series of weather observations: if viewed from January to December, they show the march of the seasons; however, if several year's worth of observations for November are examined, they show that month is rainy between 15 and 25 days 95 percent of the time. Confidence intervals in the model are not ones of rainy days, but of a range in short tons of the materiel stockpiled by particular unit at a particular time.

It is important to note that the simulations provide planners with comparative analysis instead of predictive analysis. The simulations cannot

determine how much materiel will arrive at a position, given the level of combat and interdiction. Rather, they give planners an estimate of the logistical support possible over a range of likely scenarios. Planners must then decide whether the desired combat momentum is maintainable.

C. ASSUMPTIONS

The following assumptions provide the framework within which the model operates.

1. Hostilities may occur with little to no notice. Blue might not have time to preposition materiel in theater.

2. Blue effects timely closure in the Tactical Assembly Areas. This starts Blue with a full complement of logistics users.

3. Chemical, Biological, and Radiological (CBR) agents are not used. The scope of logistically supporting a war in a CBR environment is beyond the scope of this analysis.

4. Logistics support is a discrete process. Materiel arrives in individual vehicles in specific amounts at specific times.

5. The FLB has an airfield, a seaport, railheads, highways and nearby beaches suitable for JLOTS operations.

D. MEASURES OF EFFECTIVENESS

Days of Supply and Events of Supply are the two indicators of sustainability used as measures of effectiveness. The measure used for a particular commodity depends upon the rates and conditions of its use.

1. Days of Supply (DOS)

DOS is the ratio of the remaining material on hand after consumption each day to the material used each day. This number is an indicator of how many more days the unit will have that material. DOS is the MOE for items consumed in a regular predictable fashion. Items like water and food rations are well suited to measure with DOS since their usage rate can be meaningfully expressed as a function of time. Equation 2.1 defines days of supply:

$$DOS_i = \frac{Onhand_i}{Usage_i} \qquad \forall i \qquad (2.1)$$

where $Onhand_i$ is the STONS of supply class i available. $Usage_i$ is the STONS of supply class i used each day. $Usage_i$ is determined from logistics planning factors appropriate to the level of combat activity. The classes of supply are discussed in Chapter III, Section F. Shortfalls in supply occur when DOS falls below an acceptable level determined by military planners.

2. Events of Supply (EOS)

Blue forces consume other commodities at rates that cannot be reasonably predicted as a function of time. Items such as ammunition are used conditionally. Ammunition is used in combat at a rate determined by the pace of combat. EOS is the ratio of the remaining materiel onhand after consumption to the materiel used in each event of usage. Equation 2.2 expresses this relationship.

$$EOS_i = \frac{Onhand_i}{\frac{1}{N}\sum_{l=1}^{N} Used_{i,l}} \qquad \forall i \qquad (2.2)$$

$Used_{i,l}$ is the amount of supply class i materiel used in the lth of N total events expending that materiel. EOS is an indicator of how many more events the unit can undertake before running out of that materiel. Like DOS, shortfalls in EOS develop when the unit cannot meets the demands for an expected number of actions without resupply.

III. THE LOGISTICS FLOW MODEL

A. PURPOSE

The model supports the purpose of the analysis by generating a series of logistics flow snapshots in the theater. These snapshots show the logistics receipt, staging, onward movement, and integration (RSO&I) flow as the campaign progresses. After the model is replicated many times, all of the corresponding snapshots from each run are combined to form the confidence intervals.

The primary function of the model is to generate logistics flow into the theater and forward logistics base, and onward to the supported units. The logistics flow is generated with four consumption mechanisms that interact to consume materiel and create logistics needs. These mechanisms are Blue movement, Blue combat with Red, Red interdiction of lines of communication and intermodal infrastructures, and Blue interdiction repair processes.

B. MODEL CONCEPT

Conceptually, the model portrays theater logistics flow supporting one of two forces in conflict. The supported Blue forces are advancing upon an objective held by the Red forces. Red attempts to stop Blue with direct combat and interdiction efforts. Logistics materiel flows into the theater all the while. Both Blue and RSO&I depend upon the conditions of the various intermodal infrastructures: impassable roads, dropped bridges, and blown tunnels delay obtaining the objective or supporting the combat force. The infrastructures might be damaged by limited Blue strikes, by Red scorched earth tactics before they are captured, or through Red interdiction afterwards.

The model is a multi-commodity, multi-depot, transport mode time-phased network. Network constraints include road and seaport throughput, Red interdiction efforts, and Blue's rate of advance. The mathematical description of the logistics flow and attacker advance provides a feasible region for the simulation to play to various ends.

From a design point of view, the model must be both abstract enough for manageable implementation and analysis, yet sufficiently concrete to retain enough fidelity to capture the essence of the real world events it mimics. Figure 3.1 illustrates the basic data structure of the model.

To provide logistics snapshots, the model has to consider several factors affecting materiel throughput: LOC's, the pace of combat, intermodal

infrastructure conditions, and the availability of certain classes of supply. The model captures materiel RSO&I and consumption, allowing Blue to advance upon the objective in a reasonably lifelike fashion.

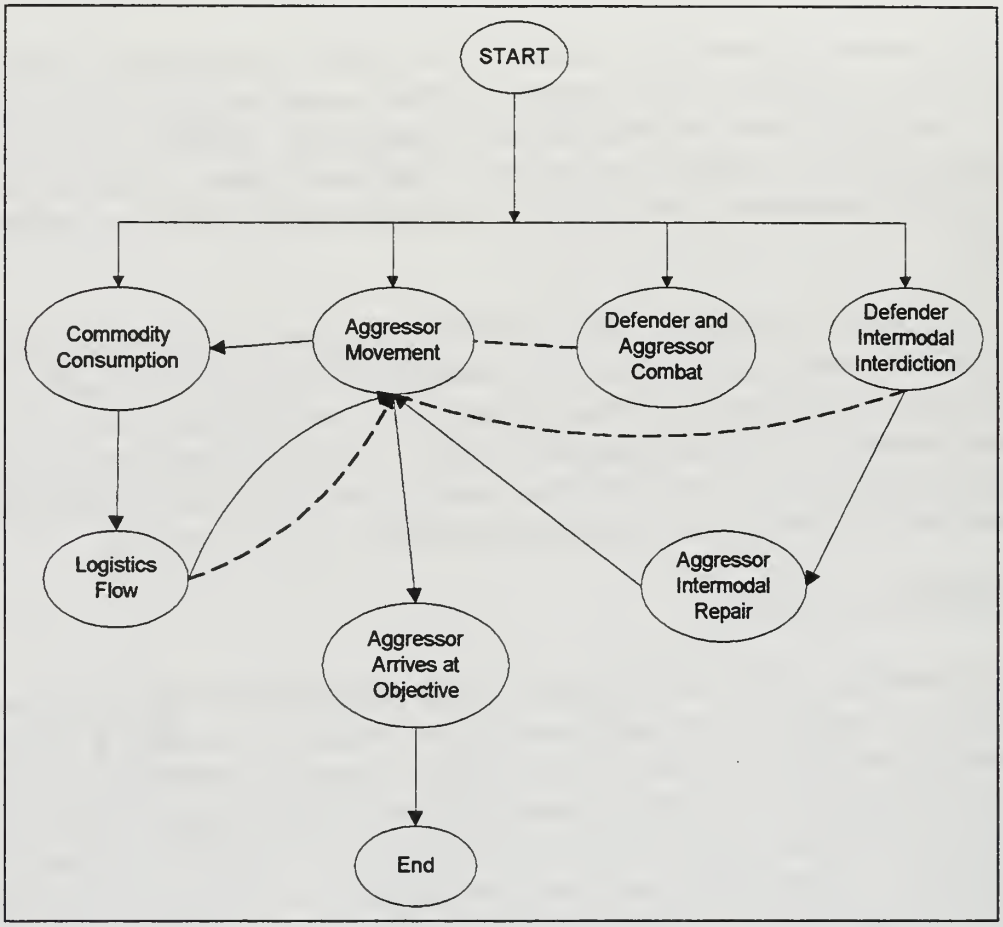

Figure 3.1. Model Functional Description. Logistics RSO&I lies at the heart of the model, spurred by various consumption processes. Scheduling events are depicted by solid lines, while canceling processes are shown with dotted lines.

Consumption is a function of both materiel usage, as through movement, and destruction, as through interdiction. Materiel usage rates vary with the aggressor's activities. Some rates, like subsistence materiel, are fairly constant despite activity; while others, like ammunition and POL, will vary greatly.

Since the goal of the analysis is to determine what levels of logistical support the campaign might have, the simulation cannot occur in a logistics vacuum. Some interaction between supplies on hand and activity must occur. For instance, it would be impossible for Blue to advance if there is no fuel, ammunition, or subsistence on hand.

C. DATA STRUCTURE

The data structure organizes information into a format which supports the model and ensures that the necessary data are available to the functions that must manipulate them. Three broad areas are supported, as shown in Figure 3.2: a network, a logistics delivery system, and a force structure system. (See Appendix A for a description of the model mapping form.)

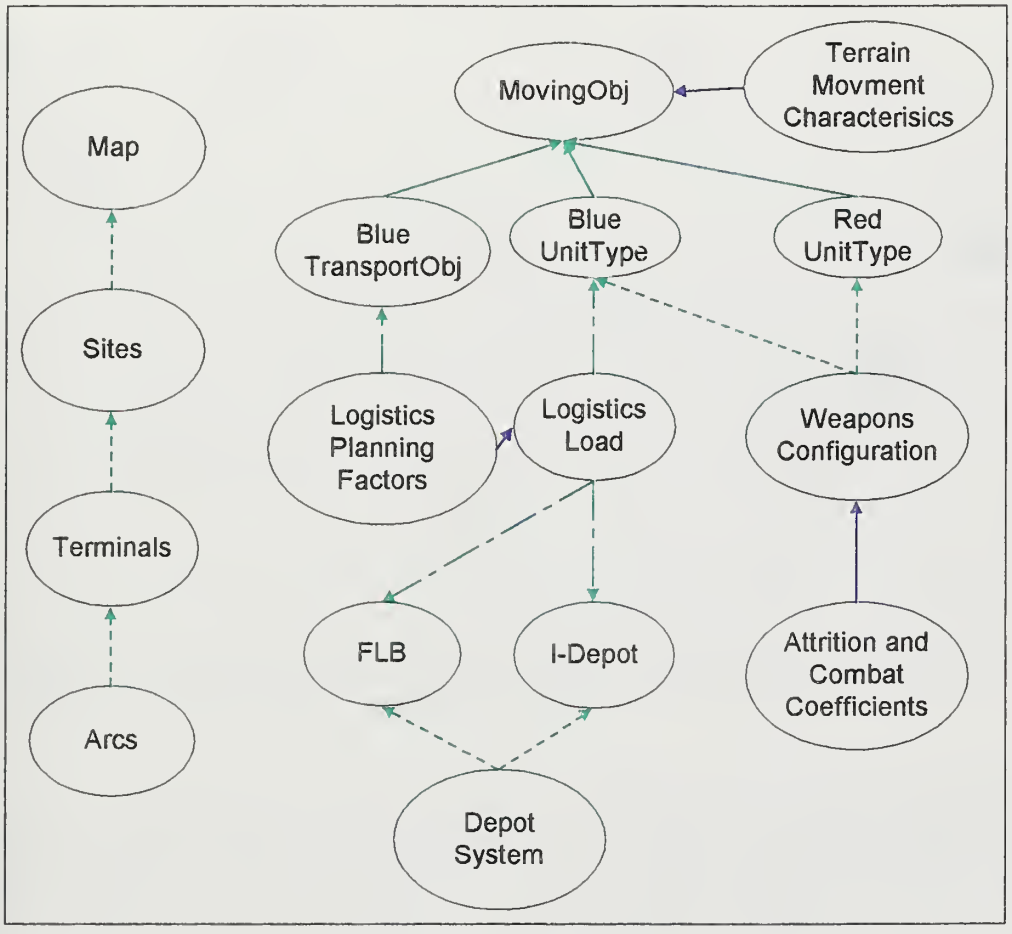

Figure 3.2. Basic object-oriented model data structure. The model uses a map upon which Blue and Red forces move. A depot system composed of a forward logistics base and intermediate depots supplies Blue.

1. The Network

All the processes of Figure 3.1 rely upon a geographical representation of a map as a network. Intermodal infrastructures such as rail heads, air ports, sea terminals, highway junctions, and tunnels are represented on the map. Nearby intermodal infrastructures are bundled together as network nodes, as shown in Figure 3.3. Materiel may move freely between these collocated infrastructures:

materiel may be directly moved from the sea port to the rail station if they are in the same geographic location. All nodes with air intermodal infrastructures are connected, as are those with sea infrastructures. The relationship between Figures 3.2 and 3.3 is the network representation of the map. The sites in the data structure are the collections of the various intermodal infrastructures, or terminals. Terminals are connected to other terminals at other sites with arcs.

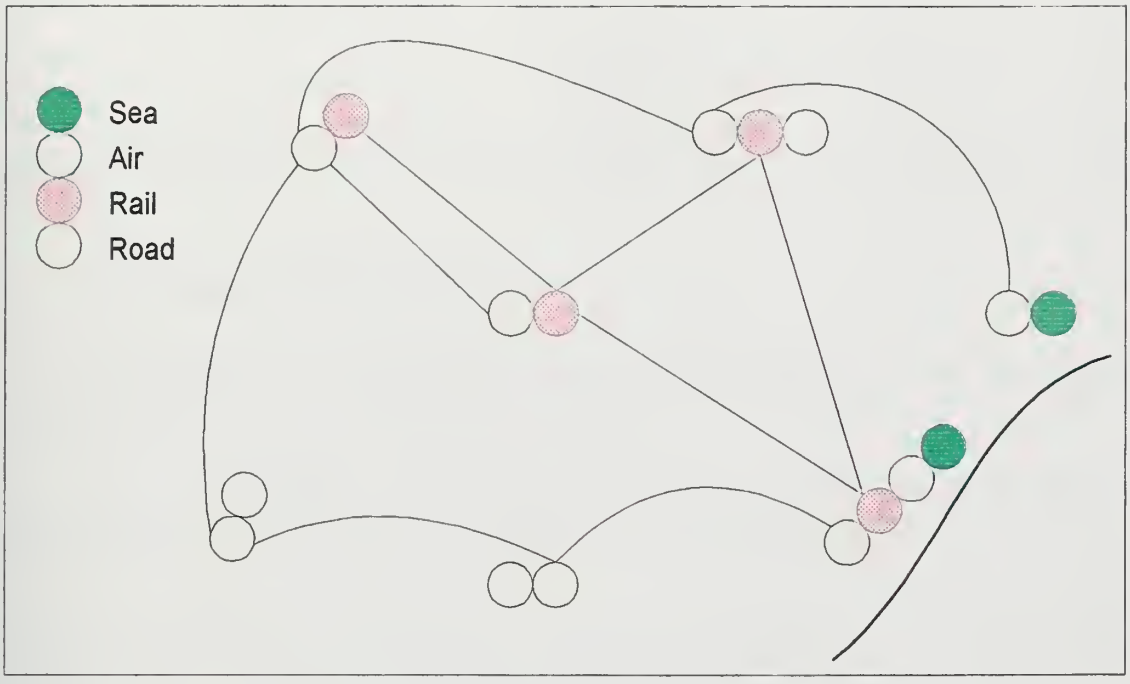

Figure 3.3. Network concept diagram. Collocated intermodal infrastructures form nodes, representing geographic locations.

Arcs connecting the nodes represent a transportation mode between two geographic locations and exist at specific times. The arcs represent Blue's lines of communication; as Blue advances or withdraws, these lines grow and shrink. Therefore the network is dynamic; its size depends upon Blue's advance. As Blue advances, LOC's are established and are subject to interdiction by Red. If interdicted, then the arc is disestablished until Blue's engineering assets have repaired the damage.

2. Logistics Delivery System

The data structure creates elements storing the data of the logistics system described in greater detail in Section F.

3. MovingObj

The model defines an entity MovingObj that is able to move on the network. A MovingObj contains any data needed to move, such as movement speeds for various terrain types. Two children entities of MovingObj are also used: a TransportObj and a UnitType. These descendants store the additional information necessary to further define a MovingObj into many entities with special characteristics. All structures representing organizational military units are fashioned with UnitTypes. A UnitType uses other data structures that enumerate weapons configurations and capabilities. TransportObjs are the building blocks for all forms of transportation used to move supplies on the network.

D. PROBABILISTIC ELEMENTS

Uncertainty is an important aspect of the model, as it is in warfare. Uncertainty enters the model in several areas:

1. Travel delays. Units experience delays as they pass through sites. These delays are modeled with a truncated normal distribution.

2. Usage. The amounts of materiel consumed are calculated from logistics planning factors. Once they have been calculated, they are adjusted by an error factor having a normal distribution whose standard deviation is arbitrarily set as 3-5 percent of the calculated amount. The magnitude of the error factor may be adjusted as desired.

3. Theater receipt. Materiel flowing into the theater due to shortfalls experience a delay whose distribution is a truncated normal. This wait time is imposed to simulate those delays materiel shipped to the theater might experience enroute in real world operations due to such as factors as Stateside backorder, intermediate travel delays, misrouting, etc.

E. TIME

Material consumption occurring on a predictable basis is computed daily. Other consumption events are scheduled to occur whenever their condition are met. For instance, the troops feed once every twenty four hour cycle, but fight and consume ammunition only when they are in contact with the enemy. Data collection for the analysis occurs every twenty four hours after all daily occurring events have occurred.

F. FUNCTIONAL AREAS

The model operates by using its various processes to manipulate the input databases to gain useful information and insights. The primary function of the model is RSO&I. Four mechanisms use supplies: movement, combat, interdiction, and repair. Other functional areas which do not consume supplies include network management and data collection.

1. Receipt, Staging, Onward Movement, and Integration (RSO&I)

In the model, Blue uses and replenishes supplies. A forward logistics base serves as the root to Blue's theater logistics tail. Intermediate depots may support Blue along the way to the objective.

a. Aggregating the Classes of Supply

Table 3.1 shows how the general classes of supply are aggregated into three categories determined by their combat utility. Primary categories are essential to the effectiveness of the unit and are tracked by themselves. Secondary categories are necessary to the unit, but can be tracked as an aggregated group. Tertiary categories are nonessential and are discarded.

Supply Class	Aggregated Class	Category	Description
I	I	Primary	Subsistence
II	II	Secondary	Clothing, etc.
III	III	Primary	POL
IV	II	Secondary	Construction
V	V	Primary	Ammunition
VI	Discard	Tertiary	Personal
VII	VII	Primary	Major End Items
VIII	II	Secondary	Medical
XI	Discard	Tertiary	Repair
X	Discard	Tertiary	Nonmilitary

Table 3.1. Aggregated supply class list. The five aggregated classes used in the model are (I) subsistence, (II) super, (III) POL, (V) ammunition, and (VII) major. Supply classes II, IV, and VIII are the classes contained in the aggregated super class. With the exception of aggregated class II (super), the aggregated class number is the same as the supply class number.

b. Logistics Flow

The logistics flow is a pull system in which the supported units use supplies and replace them by using generated requests to cause a delivery system to transport replacement materiel. Each time materiel is consumed, the unit checks that commodity's amount on hand against that commodity's capacity, reorder percent, and amount already on order. When the amounts on hand fall below the reorder point, adjusted for amounts already on order, then requisitions are generated. Each requisition is assigned a priority. The initial priority sets to a default for the unit type making the request. The higher the priority number, the higher the priority of the requisition.

The requisition enters the depot system and is sent either to the closest intermediate depot, if there is one, or to the forward logistics base, if no other depot is available. The depot fills what it can and backorders the rest from the next depot or from the forward logistics base. The priority of the backordered amount is increased. Materiel is pulled into the theater anytime a requisition order or backorder from the forward logistics base cannot be filled.

Requisitions are filled by the depot according to priority and stock levels. When a depot has an order ready to ship, either full or partial, the filled requisition enters the depot transportation assignment priority queue. Transportation assets are allocated to the requisition. Shortfalls in transportation cause the depot to generate a transportation asset request for the shortfall amount. Requisitions then wait in the queue until transportation is made available, either through new assets or current assets returning from deliveries. A convoy is formed when the transportation arrives and enters the network as it moves towards its supported unit customer.

2. Movement

Blue and Red movement allows Blue to advance on the objective while creating logistics demands that consume supplies. Movement on the map is constrained by the network. Blue and Red units either advance or withdraw. A Red unit moves until a Blue unit is detected, destroyed infrastructure blocks the way, or the FLB is overrun.

Blue will move as long as subsistence, POL, and ammunition are on hand, and no contact with a Red unit has been made. As soon as one of these four conditions changes, the Blue unit stops until the situation is resolved. If the Blue unit has used all of its POL, it must stop until it receives fuel. Any of the three remaining conditions might change during the wait; for example, if a Red unit comes close enough that they detect each other while Blue awaits fuel, then

they will fight. Should Blue win, the unit must continue to wait until it receives POL before it may advance.

In the case of a withdraw following a fight, the retreating unit stops at the first site after contact is lost, where it waits a period of time as described in Section D.

3. Combat

Combat between Blue and Red consumes materiel and helps determine when Blue moves. Once started, combat continues until one side reaches its breakpoint or Blue runs out of ammunition. Since logistics are not tracked for Red, Red has infinite supplies. The breakpoints used for Red are, therefore, set high so that Blue is not unduly penalized.

The duration of the fight is the time needed for Red or Blue to reach their breakpoint, or for Blue to run out of ammunition. Since the combat model is a linear Lanchester model, the duration may be calculated at the outset of the fight. The combat model contains two sub modules; a detection model and an attrition model.

a. Detection Model

As previously discussed, the model creates a class of entities that can move called MovingObj's, as shown in Figure 3.2. These MovingObj's moving across the network must be able to determine whether their closest point of approach lies within detection range of another MovingObj. Combat occurs whenever a Blue and Red unit lie within the maximum of the two detection ranges. Whenever a TransportObj, shown in Figure 3.2, carrying supplies to its Blue unit customer is "detected", its shipment is delivered. This section develops the algorithm used for detection.

Figure 3.4 shows the kinematics for two objects, O_1 and O_2. In the model, objects move on the map from point to point on a line. Changes in direction happen when the object arrives at a node on the map and leaves it for another node in a different direction. Since speed along the route remains constant, the only times $\mathbf{v}_1$ or $\mathbf{v}_2$ may change are whenever O_1 or O_2 arrive and depart an intermediate node.

The distance between O_1 and O_2, $\left|\vec{r}_{12}(t)\right|$, is a function of time. A detection occurs whenever $\left|\vec{r}_{12}(t)\right|$ is less than the greater of d_1 and d_2. Of course, the detection must also occur before either object arrives at an

intermediate node and changes its velocity. The positions of O_1 and O_2 are expressed as functions of time in Equations 3.1 and 3.2.

$$\vec{r}_1(t) = [x_1 + v_{x_1}t]\vec{i} + [y_1 + v_{y_1}t]\vec{j} \qquad (3.1)$$

$$\vec{r}_2(t) = [x_2 + v_{x_2}t]\vec{i} + [y_2 + v_{y_2}t]\vec{j} \qquad (3.2)$$

where (x_i, y_i) is the initial position of O_i, and $v = v_{xi}\vec{i} + v_{yi}\vec{j}$ is the initial velocity of O_i. The vector component directions $\vec{i}$ and $\vec{j}$ denote the x and y axes, respectively.

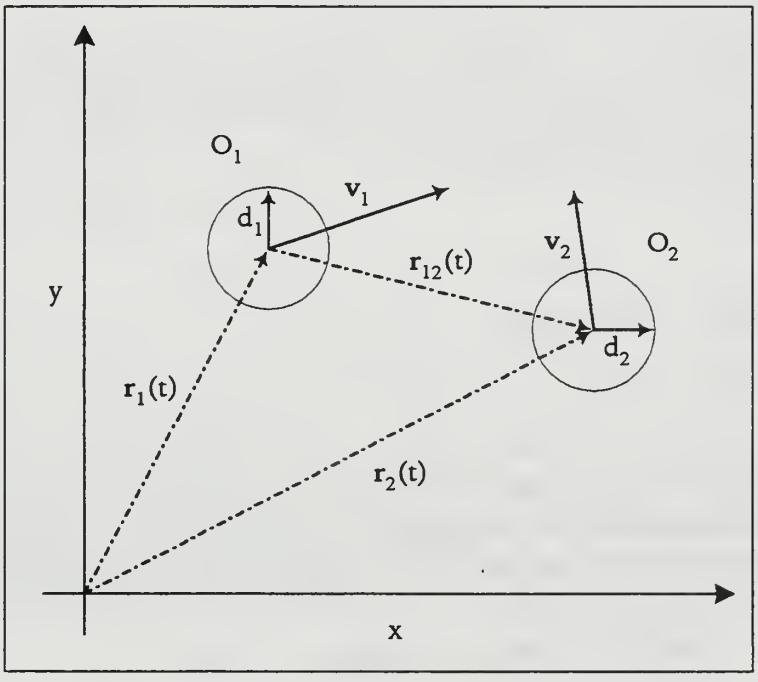

Figure 3.4. Kinematics of O_1 and O_2. The detection ranges are d_1 and d_2. The position vectors $\mathbf{r_1(t)}$ and $\mathbf{r_2(t)}$ show the initial positions, while $\mathbf{r_{12}(t)}$ is the position between the two objects. $\mathbf{v_1}$ and $\mathbf{v_2}$ are the velocities of O_1 and O_2.

The position vector describing the position of O_2 with respect to O_1 is the difference between the two position vectors. Equation 3.5 defines $\theta(t)$ as the distance between O_1 and O_2 at time t.

$$\vec{r}_{12}(t) = \vec{r}_2(t) - \vec{r}_1(t) \qquad (3.3)$$

$$\vec{r}_{12}(t) = [\Delta x(t) + \Delta v_x t]\vec{i} + [(\Delta y(t) + \Delta v_y t)]\vec{j} \qquad (3.4)$$

$$\theta(t) \equiv \left| \vec{r}_{12}(t) \right| \qquad (3.5)$$

where $\Delta x \equiv x_2(t) - x_1(t)$ and $\Delta y \equiv y_2(t) - y_1(t)$.

If O_1 and O_2 are closing, then $\theta(t)$ decreases as t approaches the time of the closest point of approach. Let t' be a time between t and the time of the closest point of approach. If O_1 and O_2 are closing, then Equation 3.6 is true. Furthermore, Equation 3.7 defines an upper bound for the value of t' since the right hand side is the soonest time O_1 and O_2 can possibly intercept each other.

$$\theta(t) > \theta(t') \qquad (3.6)$$

$$t' \leq \frac{\left|\vec{r}_{12}(t)\right|}{\left|\vec{v}_1\right| + \left|\vec{v}_2\right|} + t \qquad (3.7)$$

A special case of Equation 3.6 occurs when the closure rate is zero, but O_1 and O_2 already lie within d_1, d_2 , or both. If O_1 and O_2 are closing, then the closure time is determined by setting the distance between the objects equal to the maximum detect radius and solving for t:

$$\xi \equiv \max(d_1, d_2) \qquad (3.8)$$

$$\xi = \theta(t) \qquad (3.9)$$

$$\xi^2 = (\Delta x + \Delta v_x t)^2 + (\Delta y + \Delta v_y t)^2 \qquad (3.10)$$

$$0 = (\Delta v_x^2 + \Delta v_y^2)t^2 + 2(\Delta x \Delta v_x + \Delta y \Delta v_y)t + (\Delta x^2 + \Delta y^2 - \xi^2) \qquad (3.11)$$

The time of detection, t, is the minimum of the non-negetive quadratic roots in Equation 3.11. The special case of Equation 3.6 occurs if t=0. If t occurs before either O_1 or O_2 arrives at their respective destination, then a detection occurs.

b. Lanchester Attrition Model

The model uses a heterogeneous force Lanchester model with modified Bonder-Clark methodology for estimating the casualty rates [Ref 2]. Here, Blue is composed of $i = 1..m$ weapon types or systems, and Red has $j = 1..n$ systems. These systems are user defined. Fire allocation factors are also set by the user and proportion the amount of one weapon type firing against an opposing weapon type. For Red, ψ_{ij} is the fraction of R_j fires allocated to B_i targets. The fraction of Blue fires B_i allocated to Red targets R_j is given as β_{ji}. The further conditions that

$$\sum_i \psi_{ij} = 1 \quad \forall j \qquad (3.12)$$

$$\sum_j \beta_{ji} = 1 \quad \forall i \qquad (3.13)$$

are necessary to assure that all forces are accounted for.

The general form of the Lanchester equation used in the model is the square law modified for heterogeneous forces. The distinction between the square (aimed fire) law and linear (area fire) law is made in the calculation of the casualty rates. Equation 3.14 shows the rate at which Blue type i system is attrited by all of the Red forces. Equation 3.15 shows the same for Red.

$$\frac{dB_i}{dt} = -\sum_j A_{ij} R_j \quad \forall\, i \in 1..m \qquad (3.14)$$

$$\frac{dR_j}{dt} = -\sum_i C_{ji} B_i \quad \forall\, j \in 1..n \qquad (3.15)$$

The casualty rates A_{ij} and C_{ji} are derived using conservative estimators. To develop the casualty rates A_{ij} and C_{ji} for aimed fire, a_{ij} is defined as the rate at which one Red weapon type j attrites one Blue weapon type i. c_{ji} is similarly defined for Blue against Red. The values for a_{ij} and c_{ji} are functions of the weapon type's firing rate v and its single shot kill probability P for the target type. For Red and Blue, these become

$$a_{ij} = v_j P^r_{ij} \quad \forall\, j, i \qquad (3.16)$$

$$c_{ji} = v_i P^b_{ji} \quad \forall\, i, j \qquad (3.17)$$

Since the forces are heterogeneous, A_{ij} and C_{ji} depend not only upon the values in Equations 3.16 and 3.17, but the fire allocation factors ψ and β as well. Equations 3.18 and 3.19 develop A_{ij} and C_{ji} for aimed fire as functions of the weapon type's firing rate, its single shot kill probability against the target type, and the fraction of effort of the weapon type against the target type.

$$A_{ij} = \psi_{ij} a_{ij} = \psi_{ij} v_j P^r_{ij} \quad \forall\, j, i \qquad (3.18)$$

$$C_{ji} = \beta_{ji} c_{ji} = \beta_{ji} v_i P^b_{ji} \quad \forall\, i, j \qquad (3.19)$$

In the case of area fire, Equations 3.16 and 3.17 are modified to account for the area covered by the target and the target density. Equations 3.20 and 3.21 show these modified equations:

$$A_{ij} = \psi_{ij} v_j P^r_{ij} \left(\frac{L_j B_i}{D_i}\right) \quad \forall j, i \qquad (3.20)$$

$$C_{ji} = \beta_{ji} v_i P^b_{ji} \left(\frac{L_i R_j}{D_j}\right) \quad \forall i, j \qquad (3.21)$$

where L is the lethal area of one round from weapon type i or j
D is the total target area of the Blue or Red unit.

Finally, Equation 3.18 or 3.20, as appropriate to the type of fire, is substituted into Equation 3.14 for Blue force attrition, and Equation 3.19 or 3.21 is substituted into Equation 3.15 for Red force attrition.

4. Interdiction

Red interdicts Blue's lines of communication, intermodal infrastructures, and convoys according to a Poisson Process whose rate is set by the user. Figure 3.5 shows Red's interdiction process.

When an infrastructure interdiction occurs, RSO&I and Blue movement through the affected structure halts. When convoys are interdicted, the fraction of the requisition proportional to the fraction of the convoy destroyed is also destroyed. A requisition then enters the depot system for the destroyed amount. The destroyed convoy units are removed as potential resources from the depot transportation queue from which they were borrowed. They are not replaced until that depot transportation queue experiences a transport shortfall and requisitions more units for its queue.

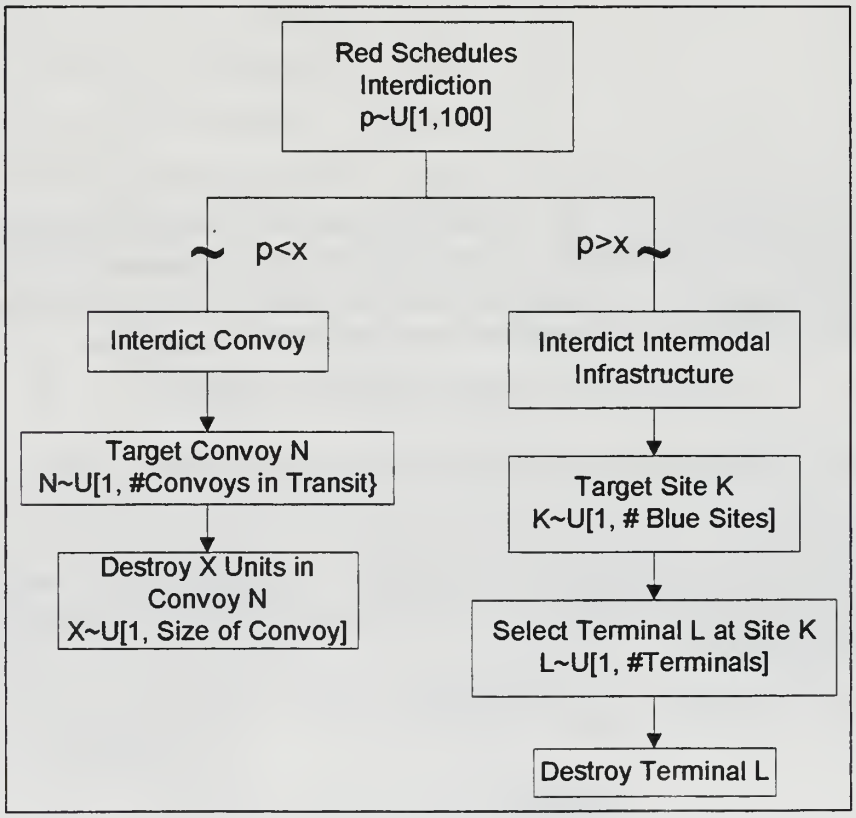
Red Schedules Interdiction p~U[1,100]
p<x
p>x
Interdict Convoy
Interdict Intermodal Infrastructure
Target Convoy N N~U[1, #Convoys in Transit}
Target Site K K~U[1, # Blue Sites]
Destroy X Units in Convoy N X~U[1, Size of Convoy]
Select Terminal L at Site K L~U[1, #Terminals]
Destroy Terminal L

Figure 3.5. Red Interdiction Process. Interdiction occurs at rate λ set by the user. The determinator, x, between convoy and infrastructure interdiction is also set by the user.

5. Interdiction Repair

When intermodal infrastructure is damaged, Blue engineer units are ordered on scene to repair the damages. Estimates for the times of repair and amounts of construction materiel consumed are based upon the capabilities of the Army's Corps of Engineers, the Navy's Seabees, and the Air Force's Red Horse Squadrons to repair standard types of battle damage or install temporary replacement structures.

IV. THE SIMULATION

The model is implemented in MODSIM II, an object-oriented simulation language that structures both synchronous, or consecutive, program execution and asynchronous, or simultaneous, program execution to occur seamlessly [Ref 3]. The result is that the four consumption mechanisms and logistics RS0&I occur concurrently, as they would in a real world campaign. The code may be downloaded from the Internet by following links at http:\\dubhe.cc.nps.navy.mil\~ahbuss.

A run of the model is made after the user has designated the forces on both sides, the rate at which interdiction occurs, and what depots are available to Blue forces. The simulation is run until the desired confidence interval is obtained. The initial data are reset prior to each new run of the model. The next sections describe the implementation of the model using MODSIM II.

A. DATA STRUCTURE

The data structure follows the form shown in Figure 3.2. Figure B.1 of Appendix B shows how the data structure has been implemented in code.

B. MOVINGOBJ STATE SPACES

MODSIM has some peculiarities in how it interrupts object activities once they have begun asynchronous activities. Suppose, for instance, a Blue unit pauses at a site before proceeding. While Blue is paused, a Red unit closes, a detection occurs, and the two units fight. In order for the code to support this sequence of events, it must interrupt both Blue's wait and Red's advance, and then send both of them into a fight. Several problems arise. MODSIM must know to interrupt Blue's wait procedures and not its move procedures, and interrupt just the opposite procedures for Red. Furthermore, once the two MovingObj's, introduced in Figure 3.2, are interrupted, each must "know" what caused the interruption to "know" what to do.

The model assigns a numeric state to each MovingObj, determined by the status of several conditions, that compels it to perform one of four activities: move, fight, wait, or withdraw. Conditions to which both sides are subject are contact with another MovingObj, arrival at the final destination, and an imposed wait at an intermediate destination. The imposed wait is a condition experienced when a unit arrives at a destination and waits before proceeding, as described in Chapter III, Section D. Blue checks the further conditions of sufficient subsistence, POL, and ammunition on hand.

For example, if a Blue unit is not waiting at a site, has not reached its objective, has sufficient subsistence, POL, and ammunition, and has not detected another MovingObj, it should advance. This set of conditions is unique to state 14 and maps onto an action to advance. Tables 4.1 and 4.2 show the conditions, their corresponding states, and the actions onto which the states map.

Delay	At Objective	Subsistence	POL	Ammo	Contact	Option	Result
+/- 32	+/- 16	+/- 8	+/- 4	+/- 2	+/- 1		
0	0	0	0	0	0	0	Wait
0	0	0	0	0	1	1	Wait
0	0	0	0	1	0	2	Wait
0	0	0	0	1	1	3	Fight
0	0	0	1	0	0	4	Wait
0	0	0	1	0	1	5	Withdraw
0	0	0	1	1	0	6	Wait
0	0	0	1	1	1	7	Fight
0	0	1	0	0	0	8	Wait
0	0	1	0	0	1	9	Wait
0	0	1	0	1	0	10	Wait
0	0	1	0	1	1	11	Fight
0	0	1	1	0	0	12	Wait
0	0	1	1	0	1	13	Withdraw
0	0	1	1	1	0	14	Advance
0	0	1	1	1	1	15	Fight
0	1	0	0	0	0	16	Wait
0	1	0	0	0	1	17	Wait
0	1	0	0	1	0	18	Wait
0	1	0	0	1	1	19	Fight
0	1	0	1	0	0	20	Wait
0	1	0	1	0	1	21	Withdraw
0	1	0	1	1	0	22	Wait
0	1	0	1	1	1	23	Fight
0	1	1	0	0	0	24	Wait
0	1	1	0	0	1	25	Wait
0	1	1	0	1	0	26	Wait
0	1	1	0	1	1	27	Fight
0	1	1	1	0	0	28	Wait
0	1	1	1	0	1	29	Withdraw
0	1	1	1	1	0	30	Wait
0	1	1	1	1	1	31	Fight

Table 4.1. State Spaces. Six conditions define the state of an object. The state determines what the object will do. States 0 to 31 are non-imposed wait states. Rows show how the status of each condition is used to form the unique binary number associated with a particular state.

Delay	At Objective	Subsistence	POL	Ammo	Contact	Option	Result
+/- 32	+/- 16	+/- 8	+/- 4	+/- 2	+/- 1		
1	0	0	0	0	0	32	Wait
1	0	0	0	0	1	33	Wait
1	0	0	0	1	0	34	Wait
1	0	0	0	1	1	35	Fight
1	0	0	1	0	0	36	Wait
1	0	0	1	0	1	37	Withdraw
1	0	0	1	1	0	38	Wait
1	0	0	1	1	1	39	Fight
1	0	1	0	0	0	40	Wait
1	0	1	0	0	1	41	Wait
1	0	1	0	1	0	42	Wait
1	0	1	0	1	1	43	Fight
1	0	1	1	0	0	44	Wait
1	0	1	1	0	1	45	Withdraw
1	0	1	1	1	0	46	Wait
1	0	1	1	1	1	47	Fight
1	1	0	0	0	0	48	Wait
1	1	0	0	0	1	49	Wait
1	1	0	0	1	0	50	Wait
1	1	0	0	1	1	51	Fight
1	1	0	1	0	0	52	Wait
1	1	0	1	0	1	53	Withdraw
1	1	0	1	1	0	54	Wait
1	1	0	1	1	1	55	Fight
1	1	1	0	0	0	56	Wait
1	1	1	0	0	1	57	Wait
1	1	1	0	1	0	58	Wait
1	1	1	0	1	1	59	Fight
1	1	1	1	0	0	60	Wait
1	1	1	1	0	1	61	Withdraw
1	1	1	1	1	0	62	Wait
1	1	1	1	1	1	63	Fight

Table 4.2. State Spaces (continued). States 32 to 63 occur when the object conducts an imposed wait. Any state greater than 2^6 is a dormant state

The state approach is based upon two guiding principles:

1. An object must be doing something that can be interrupted if it is to be interrupted.

2. An object in a state remains in that state until directed to change.

The application of the first principle is the ability of the code to interrupt the specific action that the MovingObj is performing. In the example, the code "knows" to interrupt Red's move procedures because Red's state is 14. Furthermore, because of the second principle, the code can determine the appropriate time to interrupt Red's move procedure. Continuing the example, the code directs both Red and Blue to change their states to a Fight state by interrupting their individual current activity when the detection occurs and ordering each to increase its state by 1. Both objects remain in a Fight state until one of the basic conditions for at least one object changes and precipitates a new state other than Fight. If Blue expends its ammunition in the heat of combat, but still has POL, then its state change should compel it to Withdraw. Its Fight is interrupted with an ordered state change to Withdraw, and retreat occurs.

The code can determine an object's state mathematically because each state is represented by a unique binary number based upon the conditions shown in Tables 4.1 and 4.2, which are themselves binary. The code uses the decimal conversion of the binary number as the object's state. Whenever a condition changes, the decimal state also changes. For instance, an object that runs out of POL has a state change of -4 since POL is in the 2^2 column of Tables 4.1 and 4.2.

Considering the example again from the start, the Blue unit halts at a site while the Red unit travels towards it. Blue's state is 46 (Wait) while Red's state is 14 (Move). Both increase their state by 1 when contact occurs. Also, in the case where an imposed delay is interrupted, the delay is lifted, with a corresponding change in state of -32. The net change for Blue is -31. Both states are now 15 (Fight). If Blue runs out of ammunition, its state becomes 13 (Withdraw). As the Withdraw occurs, contact is lost and the new states are 12 (Wait caused by no ammunition), and 14 (Move) for Red. When Blue replenishes its ammunition, its state changes to 14 and it advances.

One final action for MovingObj's must be considered. Each of the four actions (Move, Withdraw, Fight, and Wait) causes events to be scheduled on MODSIM's event list. The result is that the program will continue forever, well after the Red is vanquished and Blue holds the objective. Accordingly, a final state, the dormant state, is added as state 65. The dormant state does not schedule new events for the object. However, since a unique state is identified, the dormant object may be recalled into active scheduling at any time. When all of the MovingObj's in the program have become dormant, further scheduling on the event list ceases and the program terminates. A Blue unit will become dormant if a state change to 30 or 62 occurs.

C. PROGRAM COMMAND, CONTROL, AND COMMUNICATIONS

The model implementation uses two controlling authorities. The main program contains the data collection shell which directs the individual runs of the model and collects the data from them. An entity called a RefereeObj is created to control Blue and Red actions within a model run.

1. Data Collection Shell

The data collection shell serves the administrative function of collecting the data destined to form the confidence intervals and to provide data structure continuity from run to run.

2. The Referee

Each Blue and Red force component has a data structure that supports only those functions that the MovingObj needs to know or do. For instance, a MovingObj "knows" what its mission is. From this it can compute how long it will take to arrive at the next intermediate destination and how much fuel it will use getting there. It does not "know" if it will come into contact with opposing side components along the way because it has no data structure in which to store this information. This approach maintains a consistency between simulation entities and the real world units being modeled. In the real world sense, this is analogous to a combat unit that has full knowledge of its own state, but no knowledge of the patrol it is seeking.

The RefereeObj is a nearly omniscient element in the model run. It is the repository for all of the various data structures and the clearinghouse for Blue and Red MovingObj actions. In this capacity, the RefereeObj can access all of the information relevant to the model run and communicate it to Blue and Red forces on a need-to-know basis. In the example, the RefereeObj notifies both the Blue and Red components that they have made contact during Blue's move.

In its role as the clearinghouse for all MovingObj actions, the RefereeObj oversees and administers state changes for the MovingObj's. Once the RefereeObj has directed a MovingObj to change its state, it directs the MovingObj to start that state's activity: to move, fight, withdraw, or to wait. The RefereeObj then gives the MovingObj access to any data it needs to carry out the action or to handle an interrupt. The following sections describe the methodology through which the MovingObj performs its actions.

The RefereeObj uses an Oracle mechanism to order the MovingObj to action. Essentially, the MovingObj is "aware" that its state has changed and "consults" the RefereeObj as an oracle to "determine" what to do. This process is depicted in Appendix B, Figure B.6. and is coded in RefereeObj.Oracle.

The basic idea for a MovingObj action is for the RefereeObj to tell it to prepare to perform that action. The MovingObj then makes any necessary calculations, including how long to perform the action, before asking permission from RefereeObj to perform. The RefereeObj checks for potential conflicts and orders the MovingObj to act. When the MovingObj completes its action, any update bookkeeping is done, the new state is assigned, and the MovingObj consults the RefereeObj. The RefereeObj tells it to request permission to perform the new state and the cycle starts anew. When an action must be interrupted, the RefereeObj waits until the correct time and then interrupts the MovingObj. If the reason for the interrupt involves another MovingObj, then the interrupting MovingObj is interrupted as well, and both objects are told of the other's presence. Any bookkeeping is done and the object consults the RefereeObj. Figure B.7 in Appendix B shows the interrupt process.

For example, suppose a Blue MovingObj wishes to move to a specified location. The MovingObj computes how much POL it requires and how much time it will spend enroute. The MovingObj asks the RefereeObj for permission to move. The RefereeObj then checks for conflicts. In this case, the potential conflicts are meeting a Red unit, running out of POL, or finding a convoy delivering goods to it. The time of the conflict is computed. If several potential conflicts are possible, only the soonest time is retained. After the time of the first conflict is determined, the RefereeObj tells the unit to move to the specified location. The RefereeObj interrupts the MovingObj at the appropriate time if the first conflict occurs before the MovingObj arrives at its destination. The unit consumes the POL used to the time of interrupt. If, for instance, the interrupt was due a low fuel state the unit is told to request to wait when it consults the oracle. In this case, the unit will wait until a fuel convoy finds it and refuels it...if a Red unit does not find it first. If there is no conflict, then the unit completes its move and consumes the calculated POL.

D. IMPLEMENTING THE FUNCTIONAL AREAS

1. Logistics Flow Model Modules

The program uses ten modules to handle the administration and bookkeeping processes and to conduct the five functional areas.

1. ShellObj. ShellObj implements the data collection shell.

2. RefereeObj. RefereeObj contains the code for the actions performed by the Referee.

3. MovingObj. A MovingObj is the base object for all objects that move. MovingObj contains the code inherited by all objects that move.

4. OrderOfBattle. OrderOfBattle homeports Blue combat units and engineers, and Red opposition force objects. All three are children of UnitType, a direct descendant of MovingObj. OrderOfBattle also contains the Force group object. As a group object, Force acts as a "bucket" for each side into which all of each side's units are placed.

5. Logistics1. Logistics1 contains the code implementing the Depot System. It also encodes the TransportObj's; Blue children of MovingObj who move logistics materiel from the depots to the combat units and engineers.

6. MapStructure. MapStructure implements the network representation of the map used in the model. It also handles all of the bookkeeping for sites, terminals, and arcs when they are captured, interdicted, and repaired.

7. BattleData. BattleData is a field of UnitType that defines a UnitType's combat identity. BattleData is a bucket for the class WeaponObj, an object that represents the combat modeling characteristics of a single weapon system.

8. FileManager. FileManager is an administrative module that expands the built-in input/output and file handling capabilities of MODSIM II to dovetail with the needs of the code. All files input and output is accomplished using a FileManager object named FileTracker.

9. Uncertainty. Uncertainty enacts the class UncertainObj, a derivative of MODSIM's RandomObj. UncertainObj expands the methods of RandomObj to the needs of the code and serves to furnish the model with random numbers when needed.

10. SimpleStats. SimpleStats is used within the ShellObj to maintain the collected MOE data and compute the desired statistics.

2. Logistics Flow

Two elements work together to spur the logistics flow: consumption and RSO&I. Both elements are coded as a direct reflection of the model descriptions in Chapter III, Section D. Blue consumption is tracked either continuously or by events of usage depending upon which MOE is being used with that materiel. Table 3.1 cataloged the aggregated classes of supply into five aggregates: subsistence, super, POL, ammunition, and major items.

Subsistence and super are continuous consumption items for Blue units, although Blue engineers also track those construction materiel in the super class when they are repairing infrastructure. All Blue units begin scheduled subsistence and super consumption when a model run starts and ceases when the Blue units become dormant. In this process, consumption occurs every 24 hours.

Event use items are conditional use; POL, ammunition, and major items are tracked each time an event occurs that uses that commodity. POL is expended whenever a Blue MovingObj stops movement, either by reaching its destination, or by interruption. The quantity of ammunition delivered against Red units is a function of the ammunition type's firing weapon's firing rate and the length of the fight. Major items are tracked when they are destroyed and require special comment: each TransportObj and WeaponObj must have a corresponding entry in the major class so that RSO&I for these items may also occur. In other words, if a Blue division has 300 artillery pieces (WeaponType Arty) in its WeaponsList (See Appendix B, Figure B.2, Data Structure Map for UnitType), then its UnitLoadOut also will show 300 artillery pieces. When the combat module attrites these artillery pieces from the WeaponsList, they are consumed as logistics commodities as well. This duality provides the necessary link to replace major items destroyed in combat or by interdiction. Note also that infantry are considered as both major items and as a WeaponType. This allows replacement personnel to enter into the theater.

Any process of consumption causes the unit to reorder the commodity if the amount on hand plus the amounts of all of the requisitions on order falls below a user defined percent of that commodity's maximum capacity. RSO&I is triggered in this way, as is the data collection routine. The event of commodity consumption, found in Logistics1.LoadListObj.ConsumeCommodity of Appendix B, Figure B.4, passes the necessary information to the ShellObj using the RefereeObj as a messenger so that the usage data can be recorded.

3. Blue and Red Movement

MovingObj's move on command from the Referee after making the required calculations. Each MovingObj calculates its enroute time to the next destination based upon the grid distance between its initial and planned final locations and the user-defined travel speed for the terrain type between the two points. Blue MovingObj's also compute how much fuel is needed for the entire trip. In the event that the MovingObj does not have enough fuel for the trip, it is still ordered to move by the Referee and will run out of POL along the way. This is analogous to a combat unit that must advance, but may not have logistics support at its destination.

4. Blue and Red Combat

The Fight state spans elements of movement, logistics flow, and combat. The detection algorithm of Chapter III, Section F.3 determines if Blue and Red units intercept each other, or when a Blue convoy has found its Blue unit customer. In either event the objects concerned transition to a Fight state. If Blue and Red units are involved, attrition occurs. If Blue and Blue units are involved, then replenishment occurs.

The program calculates Blue and Red attrition according to Chapter III, Section F. In practice, when Blue and Red fight, the attrition calculations are made in OrderOfBattle.OpForce.Fight. Although both Blue and Red are in a Fight state, and executing the code in OrderOfBattle.CombatForce.Fight and OOB.OpForce.Fight, the actual attrition calculations are made one time in OpForce.Fight while Blue waits in CombatForce.Fight to prevent double attrition from occurring.

The duration of the fight is a function of each side's killing rate against the other, and each side's breakpoints. The rate at which a particular weapon is attrited by all opposition weapons firing at it follows Equation 3.14 or 3.15. User defined databases indicate whether a weapon type on weapon type is aimed fire or area fire, and therefore, which of Equations 3.18-3.21 to use for the casualty rate in Equation 3.14 or 3.15. Database information also tells Blue what ammunition type to use.

One side's force breakpoint is determined as a function of the component weapon type breakpoints. The database gives a minimum percent of a weapons starting strength as its breakpoint. Blue's ammunition expenditures are calculated in a fashion similar to Equations 3.15 in which the time rate of depletion is a linear function of the each weapon's firing rate and the number of

weapons firing that ammunition type. The times for ammunition expenditure are computed as a function of amount on hand and the total force rate of expenditure. Blue times to systems breakpoints actually become the sooner of weapon breakpoint and ammunition depletion.

The databases also tell the model how many of a force's weapons must fall to breakpoint before the entire force reaches breakpoint. As a result, if a force can sustain 3 of 4 systems at breakpoint before disengaging, up to two systems may be far below their individual breakpoint when contact is broken. Since Equations 3.14 and 3.15 are linear, setting the equation equal to a system's permissible casualties gives the time to its breakpoint. If the m breakpoint times for the m systems are then sorted in ascending order, a force capable of sustaining k of m breakpoints reaches force breakpoint at the kth ordered breakpoint. Whichever side's force breakpoint happens first determines the winner and the loser. Battle casualties are calculated by multiplying Equation 3.14 and 3.15 with the time to the first force breakpoint. Both sides are directed to apply a state change appropriate to the outcome of the fight.

5. Red Interdiction of Blue Intermodal Infrastructure and RSO&I

Red interdicts Blue Intermodal Infrastructure in a direct coding of Chapter III, Section 4 methodology and accompanying figure. Interdiction occurs as a Poisson Process, whose rate, lambda, is specified by the user. The code is found in OrderOfBattle.Force.Interdict.

E. MODEL OUTPUTS

The code offers a variety of output files useful for diagnostics and insights to the workings of the model. Two of these output files, the War Diary and the Supply Diary, are given in Appendix C for one of the cases presented in Chapter V.

1. Database Echoes

The Red and Blue Force dump their contents to a file. This dump lists each UnitType in the force, including the weapons characteristics for each weapon system assigned to that unit. This is useful whenever new databases are used to verify that the program has correctly constructed the data structure. The map can also be dumped in the same fashion for each run.

2. Diaries

Three history files are produced for each model run. Two of these are the War Diary and the Supply Diary. The War Diary is a listing of all non-supply related events that happen to every MovingObj in a run. For instance, the Diary lists each time a MovingObj leaves and arrives a destination, is delayed enroute, or detects another MovingObj. The Diary also logs the times and locations of infrastructure interdiction and repair.

The Supply Diary logs each event that consumes commodities, places orders and backorders, forms convoys, and delivers materiel. Since the two Diaries also list the time of occurrence, they can be compared with each other for a complete picture of the logistics flow for an individual model run.

A third historical file, a State log, can be produced for each MovingObj if desired. This Diary logs each State change of the object with the time of change, the current State, and the new State. This is a valuable diagnostic tool that is controlled using a MovingObj's StateFlow FileTracker.

3. Statistical Files

Each Blue event of commodity consumption generates two data points: the amount used and the amount remaining on hand. These data are collected by the ShellObj and provide the confidence interval statistics and MOE's for each simulation. The times of capture by Blue for each site are also collected. Examples of this output are given in Chapter V.

V. MODEL DEMONSTRATION

A. PURPOSE OF THE DEMONSTRATION

Chapter III and IV developed the proposed model and explained its implementation into MODSIM. This chapter showcases how the proposed model performs by using three cases of increasing complexity to exercise its features and functions. The results of these cases are explained in terms of how logistics affected Blue's mission, and what happened in the model to cause these effects.

B. COMMON SCENARIO AND DATABASES

In the course of a war with Red, Blue lands a division in the RedLand port city of Houston whose objective is the small town of Plainview, about six hundred miles to the north-northwest. The port city serves as the FLB. Red, caught unaware by Blue's amphibious landing, has only a division sized force garrisoned near Plainview. They rally quickly and march on Blue to force a decisive battle and interdict Blue's lines of communication and supply convoys in the meantime.

The various databases necessary to run the model are contained in Appendix D. Each database has a description of its purpose. The databases explain any unique format considerations. The numbers used for some elements are artificially high or low to slow the campaign so that RSO&I is more fully exercised.

The databases use a depot system with a FLB in Houston and two intermediate depots in Abilene and Lubbock. The Abilene depot carries mostly POL, while the depot in Lubbock carries some subsistence. The two intermediate depots are used primarily to show the depot requisition processing system that receives requisitions at the nearest depot to the troops and then fills or backorders as required.

C. MODEL CASES

One baseline and two variant cases are considered in determining the level of logistical support the supported units might expect from the FLB and the intermodal infrastructure. An instruction in RefereeObj.Oracle terminates a model run if the time exceeds 120 days, an event in which Blue's advance has stalled. Each case uses the same databases given in Appendix D.

1. Baseline

A baseline case establishes the logistics support that the supported units will have when the FLB and lines of communication operate at full capacity in an undamaged state. In an actual conflict, the baseline case is unlikely since it is doubtful any site with permanent infrastructure can be captured from the enemy entirely intact. The baseline case is germane, however because a damaged FLB operating at reduced capacity cannot be expected to sustain the supported troops if a fully functional base cannot either.

a. Model Implementation

The baseline case exercises all of the model except for combat attrition calculations, and intermodal infrastructure and convoy interdiction. It also demonstrates the statistics functions of the ShellObj and the controlling functions of the RefereeObj. The application of the baseline to the model initializes the only the Blue force data structures from the force databases.

The probabilistic elements of the baseline case are the travel time delays and usage adjustments introduced in Chapter III. The travel times are deterministic.

The expectation for the baseline case is to show the division's movement from Houston to Plainview replicated many times in order to generate statistics for Class I subsistence and Class II POL, the two aggregated classes used.

b. Results

Three hundred model runs produced the results shown in Tables 5.1, 5.2, and 5.3. Table 5.1 shows the collected statistics for the site capture times. Tables 5.2 and 5.3 shows the collected statistics for logistics materiel.

Location	N	Mean (Hours)	CI (Hours)	StdDev (Hours)	Min (Hours)	Max (Hours)
Houston	300	0.0	0.0	0.0	0.0	0.0
Abilene	300	19.1	0.0	0.0	19.1	19.1
Sweetwater	300	40.0	0.4	2.0	30.1	40.7
Lubbock	300	45.7	1.0	4.0	35.2	54.5
Abernathy	300	70.6	2.2	10.2	46.7	86.3
Plainview	300	88.8	3.0	13.1	51.8	119.1

Table 5.1. Site Capture Results. N is the number of times Blue captured the site in 300 model runs. CI gives the 95% confidence interval.

The effects of the imposed delays at the intermediate destinations can be seen in Table 5.1 as the increasing variability in site arrival times.

Not surprisingly, in the absence of intervention and combat, Blue captured Plainview in every run, since N=300 for Plainview. Table 5.2 shows the amounts of materiel that the unit had remaining when it reported its status each time an event of usage occurred. For commodities like subsistence, whose

Commodity	Day	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)
			Class I: Subsistence				
CRAT	0	300	100000.0	0.0	0.0	100000.0	100000.0
	1	300	59948.2	367.8	1624.9	55424.0	64534.0
	2	300	48832.0	3277.4	14481.3	25560.0	64245.0
	3	262	19926.5	574.0	2370.2	12377.0	25433.0
	4	43	19846.6	1086.6	1817.6	14960.0	24045.0
	Event		Class III: POL				
Motor	0	300	12000.0	0.0	0.0	12000.0	12000.0
	1	300	5884.1	55.4	245.1	4928.0	6574.0
	2	300	10011.5	473.6	2092.8	3976.0	11968.0
	3	300	8613.8	367.8	1624.9	3673.0	11446.0
	4	300	7642.0	282.2	1246.8	2704.0	11852.0

Table 5.2. Status of Materiel On Hand. This table shows the remaining amounts of materiel the unit reported after each event of usage. The second column is the day of the campaign for subsistence, and the event of usage for POL. Here, the results for C-rations and motor fuel are given. No data are given for ammunition since combat did not occur.

Commodity	Day	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)	DOS
			Class I: Subsistence					
CRAT	0	300	0.0	0.0	0.0	0.0	0.0	NA
	1	300	40051.8	367.8	1624.9	35466.0	44576.0	1.5
	2	300	40018.6	375.2	1658.1	35755.0	44355.0	1.2
	3	262	40040.4	419.0	1730.5	35688.0	45209.0	0.5
	4	43	40336.9	765.2	1280.1	37082.0	43190.0	0.5
	Event		Class III: POL					EOS
Motor	0	300	0	0.0	0	0	0	NA
	1	300	6115.9	55.4	245.1	5426	7072	1.0
	2	300	1209.7	56.0	247.8	32	1421	8.3
	3	300	1621.1	24.4	107.6	554	1804	5.3
	4	300	1535.2	71.4	315.1	63	1801	5.0

Table 5.3. Materiel usage summary. This table shows the average short tons of materiel used during each event of usage. As in Table 5.2, the second column counts days for subsistence, and event of usage for POL. The appropriate MOE for a commodity is given in the last column as the ratio of the *i*th day (event) amount remaining from Table 5.2 and the corresponding average amount used in that event from Table 5.3.

MOE is measured in DOS, the second column of Table 5.2 counts the day of the campaign. For example, note that every run had at least two days of subsistence consumption and none had more than four days. This is consistent with Table 5.1; in all runs, Plainview was captured no sooner than 51.8 hours into the campaign, and no later than 119.1 hours. Viewed another way, the campaign lasted three days in 262 runs, and four days in 43 runs. The second column of table shows that four events of POL usage occurred in every run.

Table 5.3 tabulates the average amounts of each materiel that were used during each event. The last column shows the appropriate MOE for the materiel. This column shows that Blue started to see the effects of lengthened lines of communication, particularly for subsistence, after day two. A small intermediate fuel depot in Abilene delayed this decline for POL until the third event of usage, which placed Blue in Lubbock. If the objective were further, it is likely that Blue would have run out of subsistence along the way and been forced to stop and await resupply.

c. Model Performance

The baseline case highlights many of the proposed model's features: logistics consumption, movement, and RSO&I, as well as the underlying processes of state space operations and the detection algorithm necessary for the features to operate correctly.

Appendix C contains a sample War Diary and Supply Diary. Although these Diaries are taken from a different case, they also contain all of the features of the baseline case. The Supply Diary shows the consumption and depot system processes in action: materiel is expended and requisitioned, and convoys form when the requisitions are filled. The War Diary shows the progress of these convoys as they move to resupply their customer units. The amounts used and the size of the convoys formed are functions of the logistics planning factors found in Appendix D.

Each run adds to the statistics forming Tables 5.1-5.3. The model becomes a useful tool to the military planner with these data. Table 5.1, showing site capture data, portrays the campaign duration from the logistics modeling point of view. While not intended as a timetable prediction, the data may be useful for comparison with the timetables from models like JTLS, RESA, etc., since they are generated purely from logistics consumption and resupply considerations and not the combat considerations of these models.

The real contribution of the proposed model as a planning tool are Tables 5.2 and 5.3 that show logistics requirements over the course of the

campaign. The data from various courses of action may be compared to spotlight courses that are more feasible logistically, as measured by the confidence intervals and the MOE's. Considered for a single course of action, the data provide entering arguments for planning and meeting campaign logistics requirements.

2. Variant 1: Red Interdiction

The first variant of the baseline considers the case in which Red's only preventive actions are interdicting intermodal infrastructure and convoys.

a. Model Implementation

This variant introduces intermodal infrastructure and convoy interdiction to the model functional areas and processes of the baseline case as described in Chapter III, Section D.

In addition to the probabilistic and deterministic elements already used, Variant I adds these probabilistic elements:

1. Red interdiction missions arriving at an exponential rate.

2. Target selection following a uniform distribution; one to "decide" whether to destroy an infrastructure or a convoy, and a second to select the individual infrastructure or convoy. In the case of convoy selection, a third uniform distribution determines how many of the units are destroyed.

3. An adjustment to infrastructure repair times following a truncated normal, similar to the consumption adjustment applied in Chapter III, Section D.

This variant demonstrates that logistics interdiction slows Blue's advance, either by constricting logistics flow or by destroying elements of that flow. The slowed advance should be evident as increased site capture times and events in which Blue is stopped alongside the highway awaiting resupply.

b. Results

Three hundred model runs were made of Variant I. Tables 5.4, 5.5, and 5.6 show the results, in the same order as Tables 5.1, 5,2 and 5.3. The wider confidence intervals and higher times of site capture in Table 5.4 shows that interdiction did delay Blue. The table also shows that for one run, Blue never did arrive in Plainview, having stalled somewhere between Sweetwater

and Lubbock, before the model run was stopped. This run indicates that the model allows for the possibility of interdiction being so severe that Blue is never resupplied.

Location	N	Mean (Hours)	CI (Hours)	StdDev (Hours)	Min (Hours)	Max (Hours)
Houston	300	0.0	0	0.0	0.0	0
Abilene	300	19.1	0	0.0	19.1	19.1
Sweetwater	300	47.6	2.5	5	27.1	197.4
Lubbock	299	58.5	3.6	7.2	31.7	243.5
Abernathy	299	86.9	4.9	9.8	46	265.8
Plainview	299	114.8	6.5	13.0	50.8	195.8

Table 5.4. Site capture results when Red interdicts Blue. Note the increased maximum capture times compared to Table 5.1..

Commodity	Day	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)
			Class I: Subsistence				
CRAT	0	300	100000.0	0.0	0.0	100000.0	100000.0
	1	300	59867.3	364.6	1610.6	55624.0	64761.0
	2	300	42598.8	3263.0	14417.3	24315.0	63394.0
	3	254	17842.4	3246.4	13198.6	0.0	63214.0
	4	122	19021.1	7489.2	21102.2	0.0	62231.0
	5	82	19357.8	8485.0	19601.0	0.0	63717.0
	6	54	19984.8	10535.4	19749.8	0.0	62602.0
	7	31	9826.9	7440.8	10568.4	0.0	31555.0
	8	19	17712.9	18026.8	20045.2	0.0	60566.0
	9	12	9619.3	18143.4	16033.4	0.0	52398.0
	10	4	17908.2	52672.8	26873.9	0.0	56839.0
	11	4	9022.8	20476.4	10447.1	0.0	18991.0
	12	4	2937.5	10410.6	5311.5	0.0	10881.0
	13	2	108.0	423.4	152.7	0.0	216.0
	14	2	0.5	2.0	0.7	0.0	1.0
	15	1	2205.0	0.0	0.0	2205.0	2205.0
	Event		Class III: POL				
Motor	0	300	12000.0	0.0	0.0	12000.0	12000.0
	1	300	5892.8	53.6	236.4	5124.0	6681.0
	2	299	9541.7	544.8	2403.1	4162.0	11980.0
	3	299	8360.8	429.2	1893.4	2809.0	11668.0
	4	299	7425.7	332.2	1465.7	2581.0	11638.0
	5	299	6256.9	303.8	1340.4	2585.0	11024.0

Table 5.5. Status of Materiel On hand. This table shows the amounts of materiel the unit reported on hand for each day (event) of usage. Ammunition is not shown since combat did not occur. In two cases, the objective was reached on the 13th day. One case Blue never arrived at Lubbock.

The effects of interdiction on logistics seen in Table 5.5 are striking. Blue was resupplied at a slower rate than the baseline case; and as indicated by the zero minimum amounts for days three through fourteen, Blue had no subsistence on hand for some runs. A comparison of the mean usage values in Table 5.6 shows a mostly declining daily subsistence consumption, despite a constant number of personnel. In other words, Blue is using less because Blue has less to use, not because there are fewer users. Occasional spikes in this subsistence data show days on which convoys carrying subsistence arrived. In the baseline case, Blue's campaign never exceeded four days; here,

Commodity	Day	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)	DOS
			Class I: Subsistence					
CRAT	0	300	0.0	0.0	0.0	0.0	0.0	NA
	1	300	40132.7	364.6	1610.6	35239.0	44376.0	1.5
	2	300	40201.4	356.0	1572.6	34909.0	45531.0	1.1
	3	254	38099.7	1059.4	4307.1	24336.0	44207.0	0.5
	4	122	31767.6	4428.0	12477.0	44.0	44901.0	0.6
	5	82	31130.9	5953.6	13752.9	10.0	43829.0	0.6
	6	54	36464.4	4672.6	8759.2	3.0	43625.0	0.5
	7	31	27765.0	10409.0	14784.5	11.0	41428.0	0.4
	8	19	34043.1	10313.0	11467.6	2.0	42897.0	0.5
	9	12	22974.1	18718.2	16541.2	32.0	42847.0	0.4
	10	4	21192.5	47867.0	24421.9	32.0	42362.0	0.8
	11	4	19597.8	44356.8	22631.0	2.0	39739.0	0.5
	12	4	18714.2	31838.4	16244.1	32.0	39603.0	0.2
	13	2	21250.0	83166.8	30004.0	34.0	42466.0	0.0
	14	2	124.5	358.6	129.4	33.0	216.0	0.0
	15	1	23371.0	0.0	0.0	23371.0	23371.0	0.1
	Event		Class III: POL					EOS
Motor	0	300	0.0	0.0	0.0	0.0	0.0	NA
	1	300	6107.2	53.6	236.4	5319.0	6876.0	1.0
	2	299	1189.5	59.8	263.6	20.0	1414.0	8.0
	3	299	1563.8	65.4	288.9	46.0	1893.0	5.3
	4	299	1559.0	62.4	275.0	99.0	1830.0	4.8
	5	299	1561.9	58.2	256.3	65.0	1842.0	4.0

Figure 5.6. Materiel usage during interdiction.

over one third of the runs exceeded four days. The data for subsistence in Table 5.5 stops at the point where resupply essentially ceased to arrive at the division.

c. Model Performance

The proposed model interdicts intermodal infrastructure and convoys, with a direct impact on Blue's sustainability as measured by the MOE's. The Diaries in Appendix C are taken from the 300th run of this variant

and show supply convoys backing up in Houston for several days after the roads from Houston were interdicted. The Diary shows convoys being ambushed and how many units were destroyed. If these ambush log entries are compared with the Supply Diary, the amount of materiel lost is seen as a new supply requisition.

The model expands its utility as a planning tool by showing potential flow bottlenecks resulting from interdiction, potential critical commodities whose failure to resupply can halt the advance, and the potential volume of commodities at risk by interdiction. These indicators can help planners place intermediate depots and preposition those items likely to be lost in ambushes but critical to the war effort. As in the baseline case, the model generated data provide entry arguments for planning requirements to meet logistics needs. The confidence intervals in Tables 5.5 and 5.6 become increasingly erratic for subsistence as the campaign continues because there are fewer instances of prolonged campaigns to generate them. In the real world sense, this is comparable to a campaign likely to last two months, but could conceivably last six. While the planner cannot use confidence intervals based on these few data points, the mean STONS used, coupled with the minimum and maximum amounts used, can still provide insights to the logistics requirements of worst case campaign outcomes for a given course of action.

3. Variant 2: Blue and Red Combat

The second variant allows Red to fight Blue in close combat, as well as by intermodal and convoy interdiction.

a. Model Implementation

This second variant completes the functions of the combat module and exercises all features of the model and the code. No new probabilistic elements are added. The combat module calculates materiel consumption deterministically as a function of the number of firers, the rate of fire, and the duration of fire. The consumption mechanism does continue to apply the usage adjustment already introduced for the other classes of aggregated supply.

This variant is implemented by initializing the Red forces. Initially located in Plainview, Red will move south until it detects Blue. A single battle is fought as described in Chapter III, Section F. The remnants of Blue continue towards Plainview and infrastructure interdiction is also enabled.

The model shows results of further stressing Blue's RSO&I by adding more convoys carrying battle-expended materials to the logistics flow.

The time of the battle will vary somewhat since both sides experience random travel delays as they pass through sites enroute towards each other.

b. Results

Tables 5.7, 5.8 and 5.9 show the results of three hundred runs in which Red fought Blue and interdicted his lines of communication. As in the first variant, the mean arrival times for this variant were longer than the baseline case, showing that Blue experienced campaign delays caused by both infrastructure and convoy interdiction and by combat

Location	N	Mean (Hours)	CI (Hours)	StdDev (Hours)	Min (Hours)	Max (Hours)
Houston	300	0	0.0	0.0	0	0
Abilene	300	19.1	0.0	0.0	19.1	19.1
Sweetwater	283	44.7	4.8	20.9	23.1	300.2
Lubbock	277	58.3	7.0	29.4	30.9	320.8
Abernathy	249	81.6	11.2	44.9	40.8	421.9
Plainview	283	104.3	15.0	60.2	42.5	300.2

Table 5.7. Site capture results when Red fights Blue and interdicts his lines of communication.

Tables 5.8 and 5.9 show that Blue experienced many subsistence shortages, considering that fully stocked Blue would use about 40000 rations daily. As in the first variant, POL levels remained high due to the small fuel depot in Abilene. The effects of combat with Red are seen from Tables 5.8 and 5.9. While Red's status is not shown, it is clear that Blue could not fight another battle of the same magnitude without resupply.

c. Model Performance

The mean site arrival times in this variant are lower than those of the first variant; a manifestation of interrupting a wait state. In many of the runs, Blue was conducting an imposed wait, or site delay, in Sweetwater when contact with Red, moving from Lubbock to Sweetwater, occurred.

The model generated attrition values using the algorithms in Chapter III, Section F. These values are reflected as the Class VII usage data in Tables 5.9. These numbers give approximations of materiel lost to combat; a calculation difficult for the military planners because of the variability involved: will battle occur? where? how much will be expended?, etc. While Table 5.9 is not necessarily predictive, it does provide the military planner with estimates for planning RSO&I to replace materiel lost in combat.

These three case demonstrations show that the proposed model simulates events in which the more Blue's lines of communication are stressed, the worse off Blue is and a longer campaign results. The confidence intervals and the MOE's provide useful indicators of Blue's logistic health. These demonstrations show that the model does quantify on hand amounts and usage as the campaign progresses. The confidence intervals and means provide useful numbers for the military planner, either as likely ranges of materiel available for events with a large number of data points, or as approximations for those with a small number.

Commodity	Day	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)
			Class I: Subsistence				
CRAT	0	300	100000.0	0	0.0	100000.0	100000
	1	300	59935.0	385.8	1705.0	54024.0	64659
	2	300	45805.5	3557	15716.7	24282.0	72298
	3	258	25022.5	3715.4	15224.2	0.0	67130
	4	134	17392.6	6480	19135.8	0.0	68477
	5	70	8291.1	7205.8	15379.6	0.0	65699
	6	40	3835.0	5727.6	9240.9	0.0	41445
	7	27	5029.9	9159.2	12141.0	0.0	51404
	8	18	600.6	1236.2	1337.9	0.0	5418
	9	7	17.3	38	25.7	0.0	72
	10	5	10919.6	42451	24215.1	0.0	54236
	11	4	3825.5	14486.2	7390.9	0.0	14911
	12	4	32.2	111.2	56.8	0.0	117
	13	4	665.2	2118	1080.7	0.0	2266
	14	3	8.7	34	15.0	0.0	26
	15	2	64.0	250.8	90.5	0.0	128
	16	2	0.0	0	0.0	0.0	0
	17	2	0.0	0	0.0	0.0	0
	18	2	129.0	70.6	25.5	111.0	147
	19	1	0.0	0	0.0	0.0	0
	20	1	35.0	0	0.0	35.0	35
	21	1	1024.0	0	0.0	1024.0	1024
	Event		Class III: POL				
Motor	0	300	12000.0	0	0.0	12000.0	12000
	1	300	5892.2	57.8	255.5	5000.0	6585
	2	283	9354.3	592.2	2541.0	4128.0	11986
	3	277	9135.9	452.8	1922.1	2945.0	11670
	4	249	8229.0	417.6	1681.2	1215.0	11302
	5	218	7082.4	340.4	1281.8	1232.0	10407

Table 5.8. Status of materiel on hand when Red fights Blue and interdicts his lines of communication.

Commodity	Event	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)
			Class V: Ammunition				
LAAW	0	300	1000	0	0.0	1000	1000
	1	296	0	0	0.0	0	0
BOMB	0	300	6000	0	0.0	6000	6000
	1	296	2658.1	32.2	141.0	2288	3094
HELLFIR	0	300	400	0	0.0	400	400
	1	296	0	0	0.0	0	0
AIM9	0	300	50	0	0.0	50	50
	1	296	0	0	0.0	0	0
NATO	0	300	0	0	0.0	0.02	0
	1	296	0	0	0.0	0	0
HE-1	0	300	400	0	0.0	400	400
	1	296	0	0	0.0	0	0
PD-1	0	300	50	0	0.0	50	50
	1	296	0	0	0.0	0	0
HE-2	0	300	0	0	0.0	0.02	0
	1	296	3470.3	142.4	625.3	1906.02	5569
PD-2	0	300	400	0	0.0	400	400
	1	296	0	0	0.0	0	0
			Class VII: Major				
MBT	0	300	256	0	0.0	256	256
	1	296	93.3	1.4	6.2	69	113
INF	0	300	17000	0	0.0	17000	17000
	1	296	9779.5	68	298.4	9040	10703
CAS	0	300	72	0	0.0	72	72
	1	296	70	0	0.0	70	70
Arty	0	300	267	0	0.0	267	267
	1	296	230.2	0.4	1.6	226	234

Figure 5.8 (Continued). Status of materiel on hand when Red fights Blue and interdicts his lines of communication.

Commodity	Day	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)	DOS
			Class I: Subsistence					
CRAT	0	300	0.0	0	0.0	0.0	0.0	NA
	1	300	40065.0	385.8	1705.0	35341.0	45976.0	1.5
	2	300	36548.9	849.6	3753.9	26457.0	45728.0	1.3
	3	258	32569.0	921.8	3776.9	25145.0	44380.0	0.8
	4	134	28392.4	3216.6	9498.4	310.0	41947.0	0.6
	5	70	21699.8	6533.8	13945.4	2.0	39122.0	0.4
	6	40	16478.7	8874.8	14318.8	21.0	42398.0	0.2
	7	27	17265.9	11943.8	15832.1	1.0	40877.0	0.3
	8	18	11085.4	13258.8	14350.2	1.0	40834.0	0.1
	9	7	4193.3	13508	9117.0	82.0	24737.0	0.0
	10	5	11071.8	29569	16866.9	1.0	40459.0	1.0
	11	4	19197.5	40769.8	20800.9	864.0	40550.0	0.2
	12	4	4561.5	13745.4	7012.9	176.0	14899.0	0.0
	13	4	9508.2	21597.6	11019.2	117.0	23089.0	0.1
	14	3	5903.3	22073.4	9753.2	199.0	17165.0	0.0
	15	2	13113.0	24355	8786.5	6900.0	19326.0	0.0
	16	2	8003.0	16628.6	5999.1	3761.0	12245.0	0.0
	17	2	14795.0	15668.2	5652.6	10798.0	18792.0	0.0
	18	2	18276.0	18388.8	6634.1	13585.0	22967.0	0.0
	19	1	147.0	0	0.0	147.0	147.0	0.0
	20	1	1044.0	0	0.0	1044.0	1044.0	0.0
	21	1	21978.0	0	0.0	21978.0	21978.0	0.0
	Event		Class III: POL					EOS
Motor	0	300	0.0	0	0.0	0.0	0.0	NA
	1	300	6107.8	57.8	255.5	5415.0	7000.0	1.0
	2	283	1153.2	74.8	320.9	14.0	1432.0	8.1
	3	277	825.8	124.8	529.5	39.0	1792.0	11.1
	4	249	1517.8	82.2	331.1	210.0	1816.0	5.4
	5	218	1589.7	57.2	215.6	58.0	1865.0	4.5

Table 5.9. Event usage when Red fights Blue and interdicts his lines of communication.

Commodity	Event	N	Mean (STONS)	CI (STONS)	StdDev (STONS)	Min (STONS)	Max (STONS)	EOS
			Class V: Ammunition					
LAAW	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	1000.0	0	0.0	1000.0	1000.0	0.0
BOMB	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	3341.9	32.2	141.0	2906.0	3712.0	0.8
HELLFIR	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	400.0	0	0.0	400.0	400.0	0.0
AIM9	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	50.0	0	0.0	50.0	50.0	0.0
NATO	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	0.0	0	0.0	0.0	0.0	NA
HE-1	0	300	0.0	0	0.0	0.0	0	NA
	1	296	400.0	0	0.0	400.0	400.0	0.0
PD-1	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	50.0	0	0.0	50.0	50.0	0.0
HE-2	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	16529.7	142.4	625.3	14431.0	18094.0	0.2
PD-2	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	400.0	0	0.0	400.0	400.0	0.0
			Class VII: Major					
MBT	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	162.7	1.4	6.2	143.0	187.0	1.6
INF	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	7220.5	68	298.4	6297.0	7960.0	2.4
CAS	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	2.0	0	0.0	2.0	2.0	36.0
Arty	0	300	0.0	0	0.0	0.0	0.0	NA
	1	296	36.8	0.4	1.6	33.0	41.0	7.3

Table 5.9 (Continued). Event usage when Red fights Blue and interdicts his lines of communication.

VI. CONCLUSIONS AND RECOMMENDATIONS

This thesis has developed a logistics flow model as a campaign planning tool to fill the gaps of investigating the effects of logistics on ground combat and maneuver arising from a general lack of logistics planning aids in modern combat models. Although the model may be implemented in any object-oriented programming language, MODSIM was used in this thesis because of its useful variety of built-in data structures and event-based program execution abilities.

Demonstrations of the model that showcased the different functional areas showed that the ground campaign suffered logistically when RSO&I was stressed through decreased flow due to interdiction and increased demand for replacing items destroyed in combat. The model outputs include 95% confidence intervals for the amounts of commodities used during the campaign. These intervals can provide military planners with insights into a plan's logistics flow when they are compared with those from alternative courses of action. The contribution to campaign planning is a tool that measures a force's sustainability in Days of Supply and Events of Supply, derived from combat specific consumption mechanisms, to help determine the feasibility of a potential course of action.

The basic model described in Chapter III uses several sophisticated techniques to view theater level logistics flow. It has the ability to flow materiel using many transportation modes like rail, air, boat and barge, Joint Logistics Over the Shore, and others. The map network extends itself to multiple lines of advance in different directions. The detection sub-model of the combat model eases the transition to event-flow programming by determining in advance when events will occur so that alternative time-step methods are not required. The attrition sub-model of the combat model is a standard model used throughout the military modeling and campaign planning communities. An object-oriented and modular design allows portions of the model to be further refined as long as the interfaces are maintained correctly. This allows the model to adapt to future needs.

Several enhancements to the model could improve its utility for campaign support:

1. An intermodal throughput capacity should be completed. Currently, the data structure stores the throughput capacities of arc, terminals, and sites. However, they are not implemented in the model because a satisfactory throughput model was not found. Rather than using the current throughput capacity as an absolute upper bound on flow for an interval, a more

desirable model would consider travel time as a function of congestion and slow flow appropriately. Since congestion is an instantaneous function, the event flow approach has difficulties unless travel time for all traffic on an arc is recomputed each time any traffic element does something that could alter congestion.

2. Encode the ability to flow troops and materiel on more than one axis of advance. Encoding this requires adding algorithms like Djikstra's algorithm to determine which arcs should be used to route logistics flow.

3. The program currently moves materiel only by road, even though both the model and the encoded data structure support numerous other modes of transportation. Completing this capability will require algorithms that prioritize among the various transports and determine which intermodal means a shipment will use. This feature should also include a Djikstra's algorithm to help determine which intermodal means is best.

This proposed model identifies and uses many basic concepts and methodologies to produce a suitable logistics analysis tool for military planners to use when comparing competing courses of action to support and develop a campaign plan. This model is also a springboard for more complex approaches to simulate and model the effects of logistics on ground combat and maneuver.

LIST OF REFERENCES

1. Pagonis, W. G. LTG, *Moving Mountains: Lessons in Leadership and Logistics from the Gulf War*,Harvard Business School Press, Boston, Massachusetts, 1992.

2. Taylor, James G., *Lanchester Models of Warfare*, Vol. II, Chapter 5, Military Operations Research Society of America, 1983.

3. MODSIM II The Language for Object-Oriented Programming, CACI Products Company, January 1993.

APPENDIX A. MAPPING THE MODEL

The goal of the model mapping is to make it visually understandable with a few uncomplicated rules. It is intended to dovetail with object-oriented languages supporting synchronous and asynchronous events, modules, user-enumerated types, and canceling events. Three basic concepts guide the process:

1. The data structure map and the process flow maps are separate. The data structure map is the basic road map for the model. It shows data substructure ownership and visibility, and where specific elements of data reside. Only the fields of the data structure are shown on the data structure map. The process flow maps show how the data structure is manipulated to execute the model. Ideally, the form, or data structure, facilitates the function, or process flow.

The model is a collection of processes operating together to accomplish a goal. Each process flow map shows only those functions that support that process. The set of process maps comprises the whole of the model flow. Completed, the model map set will have one data structure map and as many process flow maps as necessary.

2. Colors broadly identify form and function classes and elements. Table A.1 shows the colors assigned to the various forms and functions of the model. Only a few colors are used since they are not intended to show subtle nuances of model construction.

3. A few different types of shapes and arrows are used. Circles are used as connectors for records, list of passed parameters, and page breaks. Ovals are used as connectors for synchronous and asynchronous procedures. Procedures are gathered together into rectangles. If a process map uses procedures from different modules, then the procedures are drawn together and bound freehand to help show modular interaction. Form connectors, particularly for fields, records, and user-enumerated types are labeled alphabetically. Function connectors are labeled in module.object.method shorthand. For instance, a connector to a method of DepotManagerObject called FillRequisition, found in the module Logistics, might be L.DMO.FR if the connector crosses module boundaries or pages, and DMO.FR within module and page boundaries.

dotted line	Composition, or group, elements (form)
dash-dot-dash line	Fields (form)
solid line	Everything else (form and function)
Blue	Process flow inside a function
Green	Object (inheritance, field, group)
Dark Red	Asynchronous flow
Light Red	Synchronous flow
Yellow	Modules
Blue	Fields, records, user-enumerated types
Lavender	Canceling edges
Black	Header information and labels

Table A.1. Visual aid assignments

Arrows point in the direction of increasing hierarchy in form, and flow in function. Passed parameters are shown with the line. If the passed parameters are legion, then a parameter connecting circle is used. Table A.1 shows how colors and shapes are used together to express the data structure and process flow maps.

For instance, anything associated with an object is green. The data structure would use a green solid line to show that an object inherits from another with an arrow pointing from child to parent ("is-a" relationship). In a case in which one object forms a field for another object, a green dash-dot-dash line points from the field-provider object to the field-user object ("has a" relationship). The color showing the clearest depiction is used whenever several different colors might be used.

For example, refer to Figure B.6 in Appendix B. The figure shows one element of data structure, the RefereeObj, and two processes: Oracle and Intervene. The map of the RefereeObj shows that this object uses eight other objects as fields, depicted by the dot-dash-dot green lines from the field object connectors to the RefereeObj. If RefereeObj had used any user-enumerated types or records, these would have been listed in blue.

The synchronous, or sequential, Oracle method is shown in light red. An asynchronous, or simultaneous, method might be invoked from within Oracle. This method, GoDormant, is shown in dark red. Process flow inside Oracle is in blue, and orders to follow on sequential methods are red, with arrows carrying passed parameters to the method connector. Intervene uses canceling events, as shown in lavender. These events are used whenever the RefereeObj must interrupt a MovingObj's activity. If the canceling event for MO.Move is followed to the actual object interrupted, it interrupts CF.Move. This event is shown in Appendix B, Figure B.5. Note that the interrupting method connector, RO.IVN, is shown in dark red since it is an asynchronous event. Since it is also

an interrupting event, it might also be shown in lavender. This is a case when different coloring might be used for the same event. Which one is used depends upon clarity and preference.

An example of modular grouping is shown in Appendix B, Figure B.2, which shows the data structure for MovingObj. The figure shows that MovingObj draws from four modules: MovingObj, Logistics1, OrderOfBattle, and BattleData.

APPENDIX B. MODEL MAP PORTFOLIO

Appendix A describes how the model is mapped during the transition from concept and event diagrams to object oriented depiction in preparation for coding. This Appendix contains the data structure map and the various process flow maps used to implement the model. They represent the bridge between Chapter III's description of the model and Chapter IV's implementation in MODSIM.

Instead of dispersing the various figures throughout the body of the thesis, they are gathered in this Appendix to help visual understanding. The connectors are unique and refer to the same objects throughout the diagrams. The syntax of the diagrams is described in Appendix A.

These abbreviations are used in the portfolio:

SO	ShellObj
RO	RefereeObj
MO	MovingObj
F	Force
UT	UnitType
CF	CombatForce
OP	OpForce
E	Engineer
DMO	DepotManagerObj
TO	TransportObj
LPFO	LogisticsPlanningFactorsObj
FT	FileTracker
UO	UncertainObj

Figure B.1. Data Structure map of the map and depot system

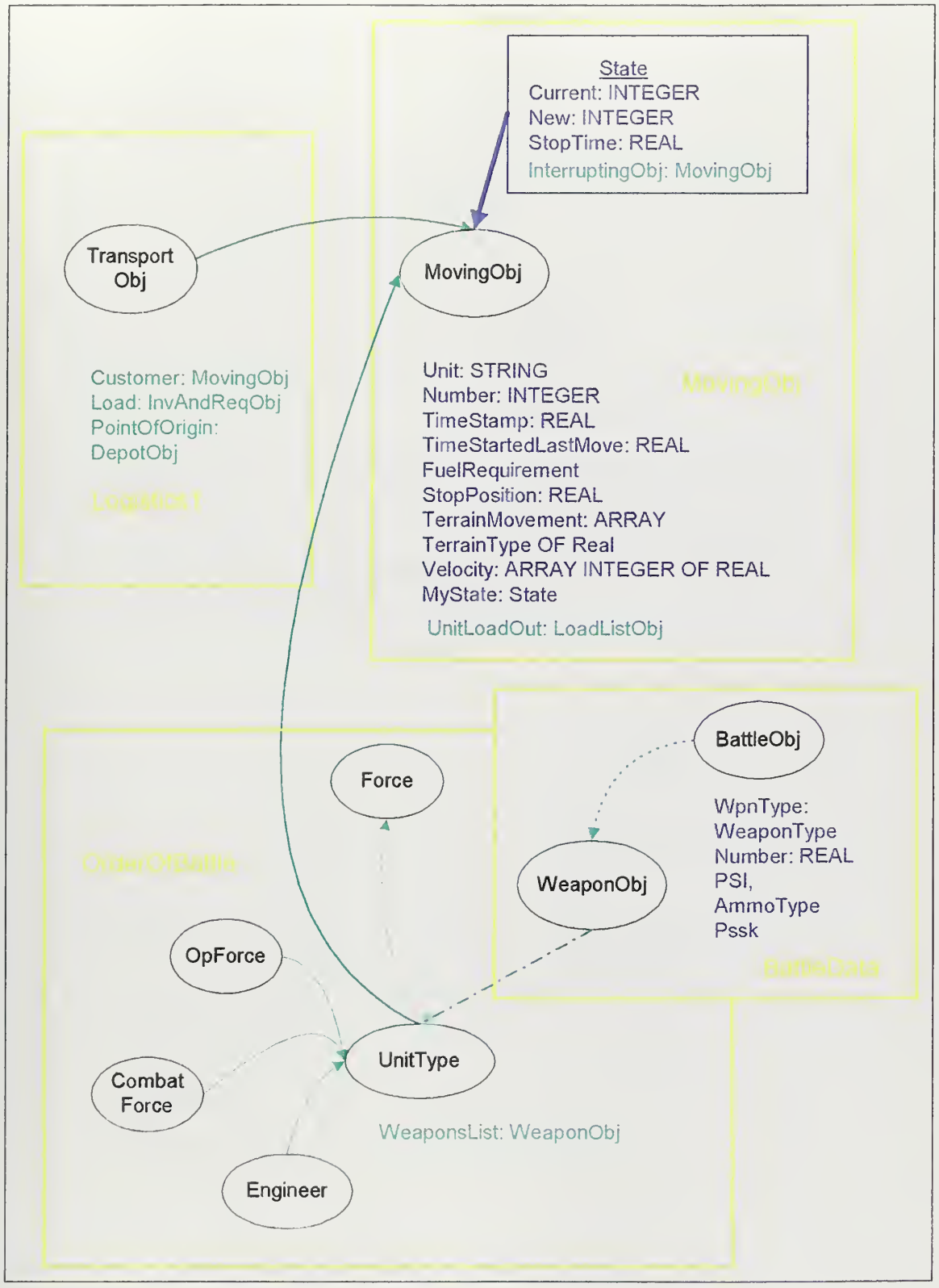

Figure B.2. Data structure map showing MovingObj and descendent architecture

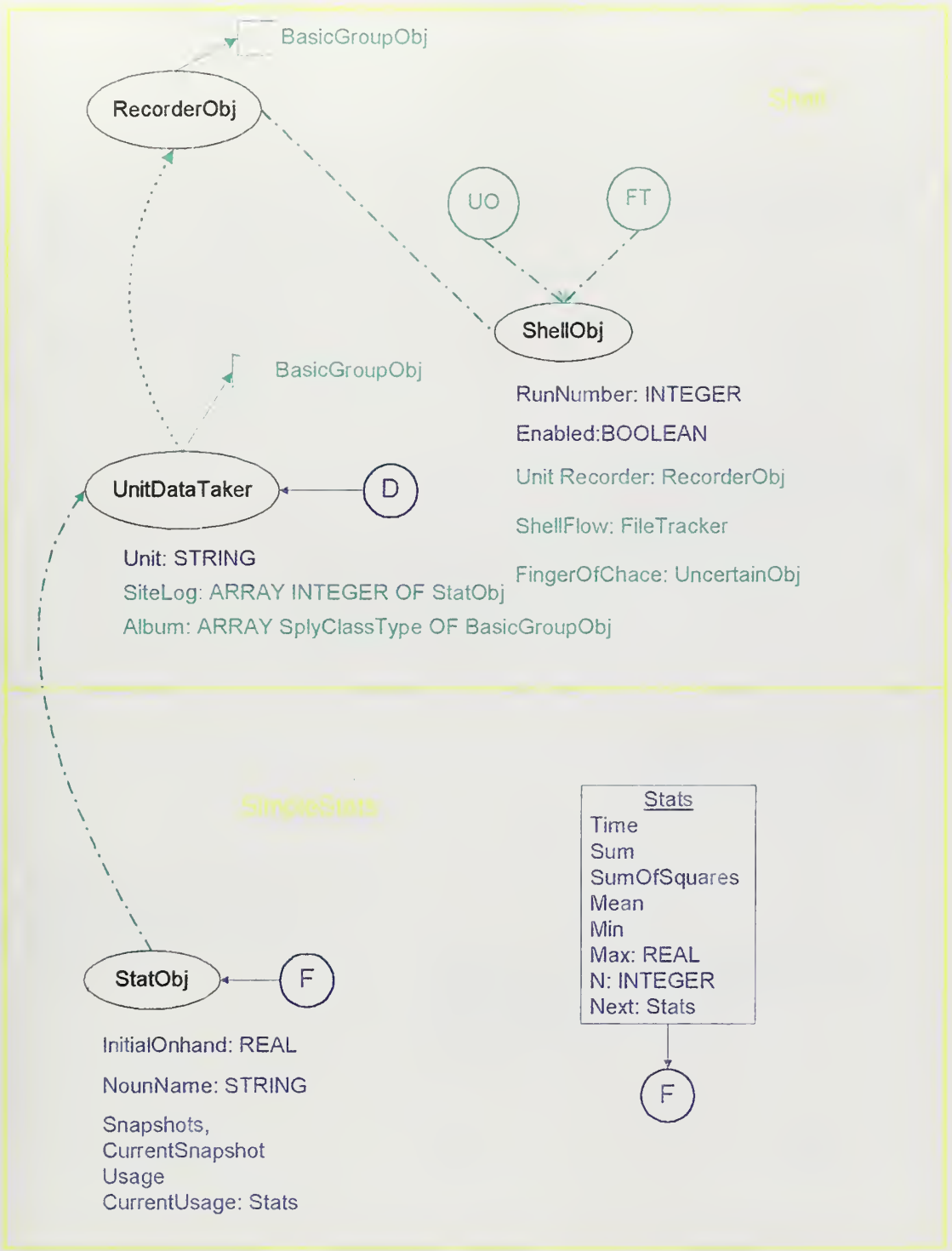

Figure B.3. Data structure map showing the data collection shell and RefereeObj

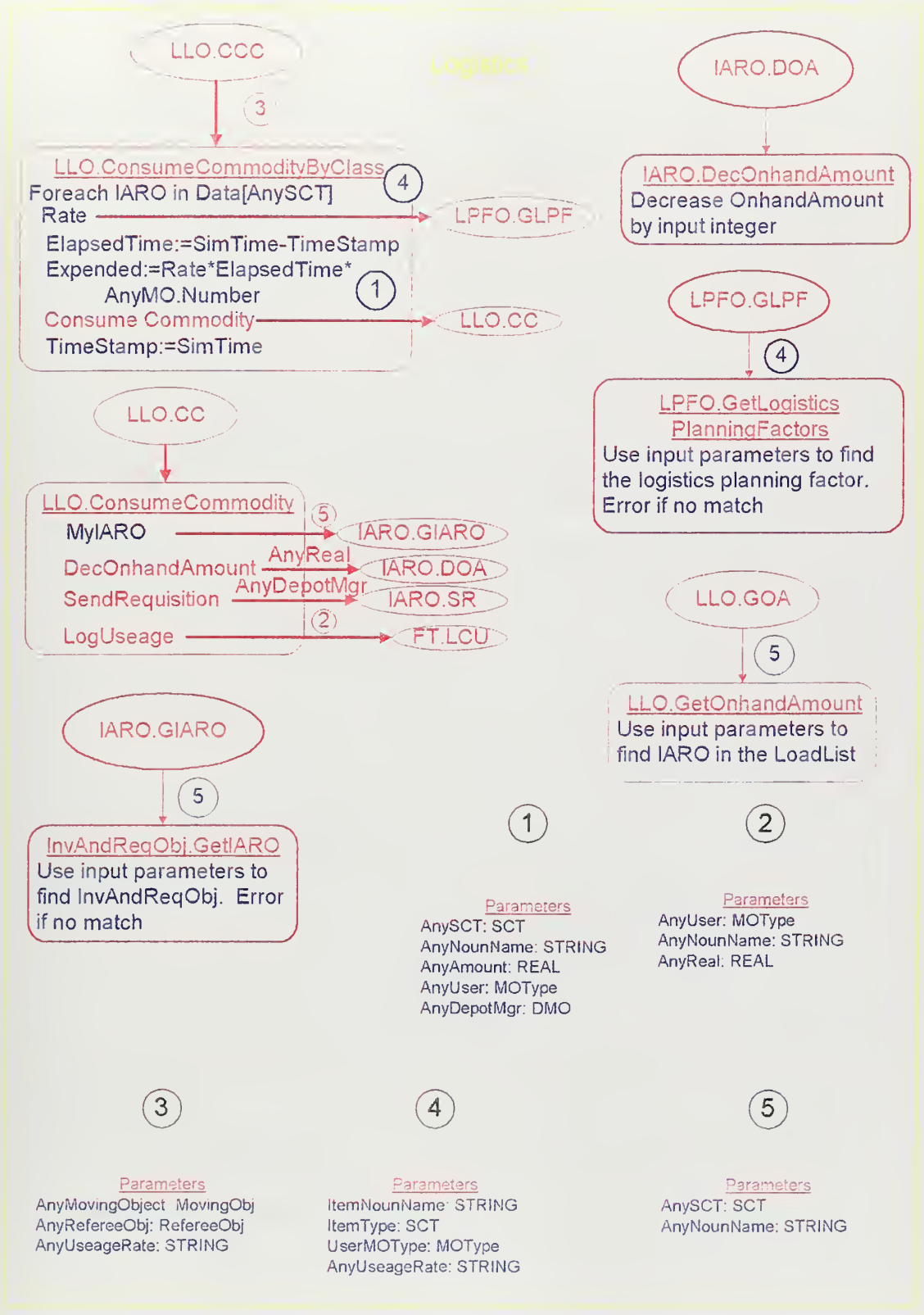

Figure B.4. Commodity consumption process flow

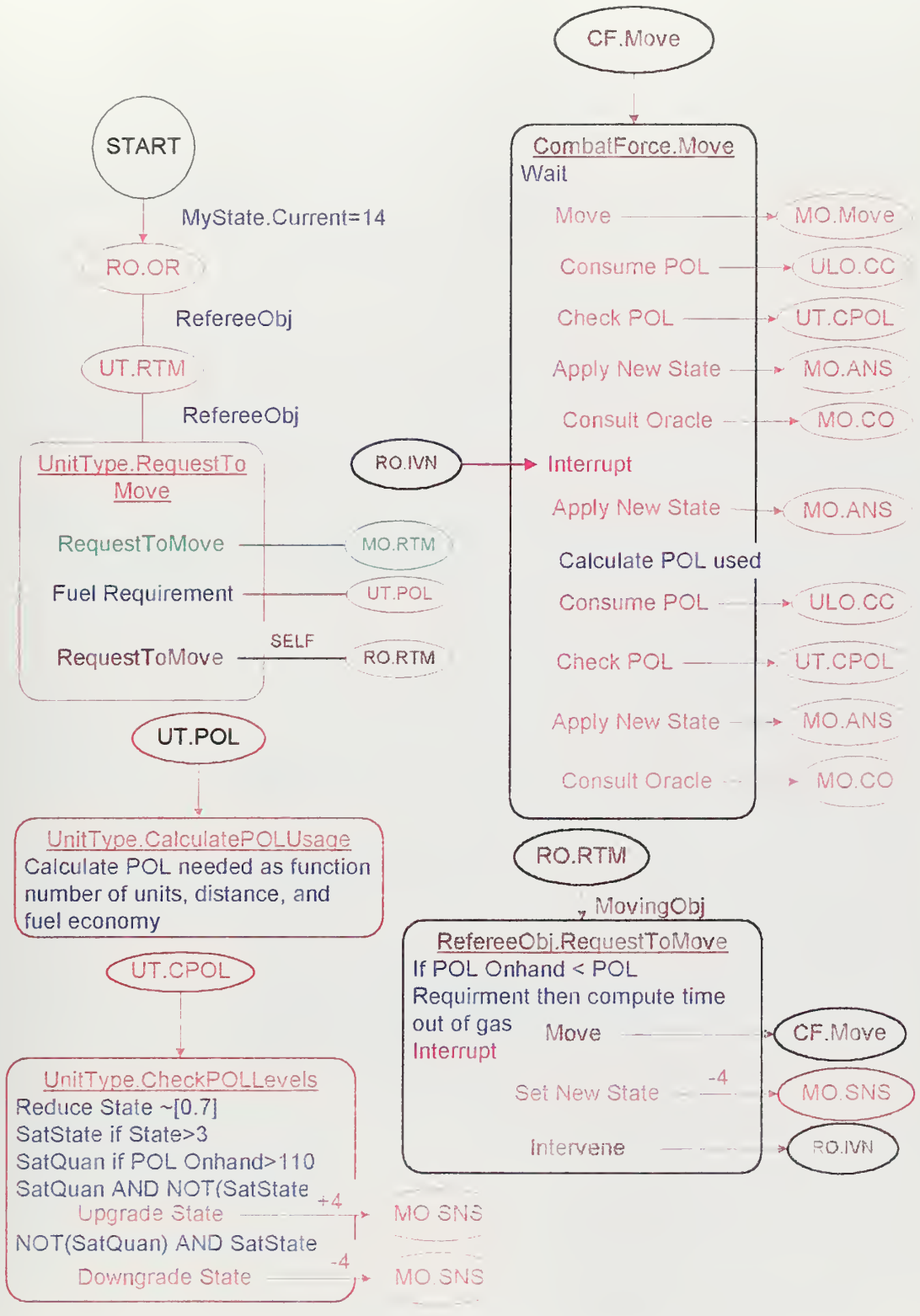

Figure B.5. POL Consumption process flow

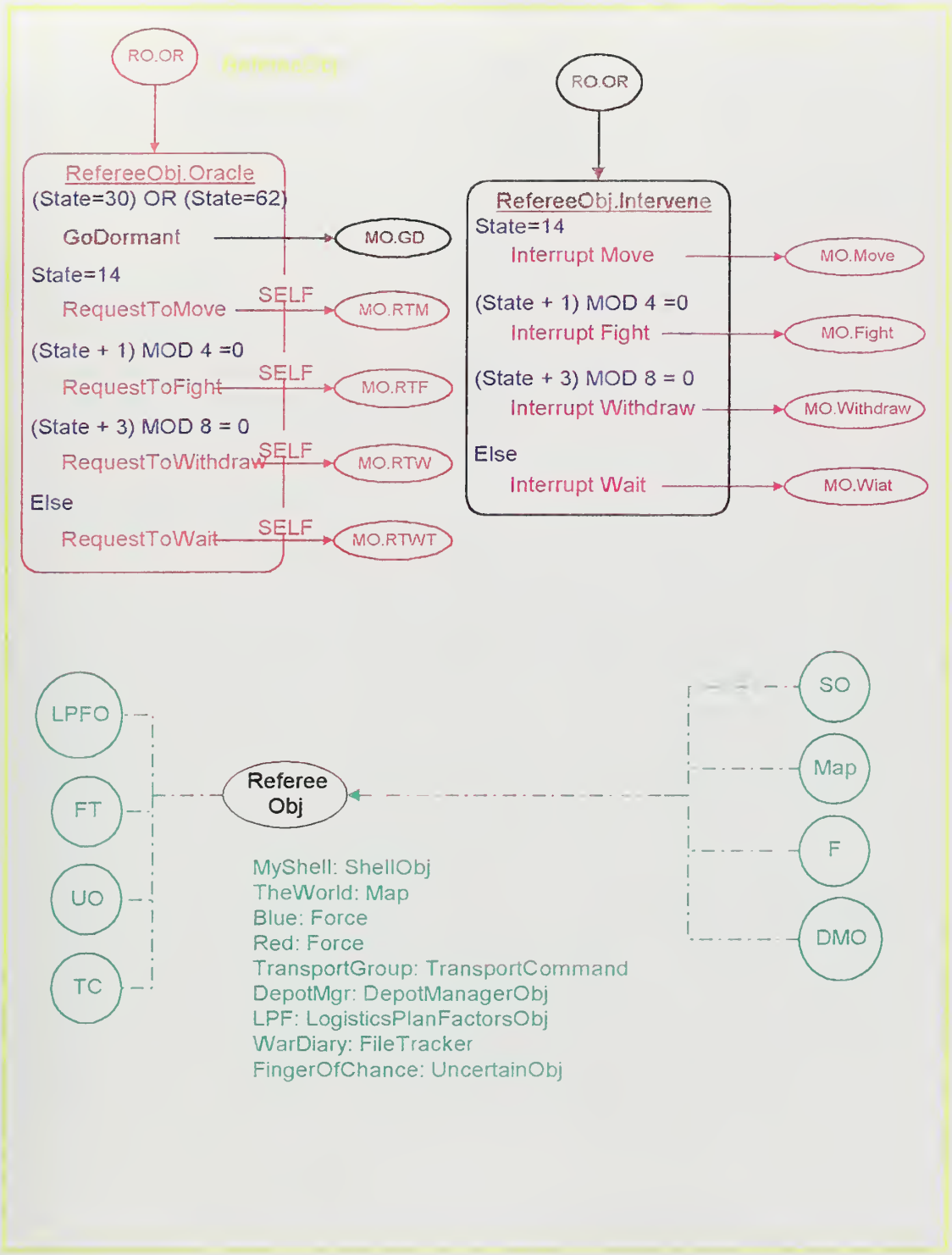

Figure B.6. The Referee and its Oracle and Intervention processes.

APPENDIX C. DIARY EXAMPLES

This Appendix gives the War and Supply Diaries for a single run of the model. These particular Diaries are taken from the last run of Variant 1: Red Interdiction, as described in Chapter V, Section C.

1. WAR DIARY

War Diary
Diary for Run 300
0.00 Houston captured
0.00 Houston depot made operational
0.00 IDiv leaving Houston and moving to Abilene191.0 miles away.
14.77 Houston's road facility interdicted.
19.10 IDiv arrived at Abilene
19.10 Abilene captured
19.10 Abilene depot made operational
19.10 IDiv started a 23.5 hour delay in transit at Abilene
19.10 Convoy1 started a 3.5 hour delay in transit at Houston
22.57 Convoy1 started a 3.9 hour delay in transit at Houston
24.00 Convoy2 started a 4.5 hour delay in transit at Houston
26.43 Convoy1 started a 5.5 hour delay in transit at Houston
28.51 Convoy2 started a 4.8 hour delay in transit at Houston
31.97 Convoy1 started a 5.9 hour delay in transit at Houston
33.31 Convoy2 started a 5.2 hour delay in transit at Houston
37.83 Convoy1 started a 5.5 hour delay in transit at Houston
38.56 Convoy2 started a 5.5 hour delay in transit at Houston
42.63 IDiv leaving Abilene and moving to Sweetwater 40.0 miles away.
43.37 Convoy1 started a 1.9 hour delay in transit at Houston
44.02 Convoy2 started a 3.9 hour delay in transit at Houston
44.27 Convoy2 was ambushed. 24 units destroyed, 5 units remaining.
44.27 Convoy2 started a 19.1 hour delay in transit at Houston
44.27 Convoy3 started a 5.2 hour delay in transit at Houston
45.26 Convoy1 started a 5.5 hour delay in transit at Houston
46.63 IDiv arrived at Sweetwater
46.63 Sweetwater captured
46.63 IDiv started a 25.5 hour delay in transit at Sweetwater
46.63 Convoy4 leaving Abilene and moving to Sweetwater 40.0 miles away.
48.00 Convoy5 started a 4.2 hour delay in transit at Houston
49.13 Convoy4 is resupplying IDiv
49.13 IDiv leaving Sweetwater and moving to Lubbock 51.0 miles away.
49.48 Convoy3 started a 4.7 hour delay in transit at Houston
50.77 Convoy1 started a 4.4 hour delay in transit at Houston

51.67 IDiv arrived at Lubbock
51.67 Lubbock captured
51.67 Lubbock depot made operational
51.67 IDiv started a 30.6 hour delay in transit at Lubbock
51.67 Convoy6 leaving Abilene and moving to Sweetwater 40.0 miles away.
52.15 Convoy5 started a 5.2 hour delay in transit at Houston
54.19 Convoy3 started a 5.4 hour delay in transit at Houston
55.17 Convoy1 started a 5.0 hour delay in transit at Houston
55.67 Convoy6 arrived at Sweetwater
55.67 Convoy6 started a 4.0 hour delay in transit at Sweetwater
57.32 Convoy5 started a 5.4 hour delay in transit at Houston
59.57 Convoy3 started a 6.3 hour delay in transit at Houston
59.67 Convoy6 leaving Sweetwater and moving to Lubbock 51.0 miles away.
60.15 Convoy1 started a 3.4 hour delay in transit at Houston
62.07 Convoy6 is resupplying IDiv
62.07 IDiv leaving Lubbock and moving to Abernathy 51.0 miles away.
62.74 Convoy5 started a 3.3 hour delay in transit at Houston
63.38 Convoy2 started a 5.0 hour delay in transit at Houston
63.57 Convoy1 started a 2.4 hour delay in transit at Houston
64.62 IDiv arrived at Abernathy
64.62 Abernathy captured
64.62 IDiv started a 21.2 hour delay in transit at Abernathy
64.62 Convoy7 leaving Lubbock and moving to Abernathy 51.0 miles away.
65.85 Convoy3 started a 4.1 hour delay in transit at Houston
65.94 Convoy1 started a 4.4 hour delay in transit at Houston
66.00 Convoy5 started a 3.9 hour delay in transit at Houston
67.02 Convoy7 is resupplying IDiv
67.02 IDiv leaving Abernathy and moving to Plainview 51.0 miles away.
68.33 Convoy2 started a 4.5 hour delay in transit at Houston
69.57 IDiv arrived at Plainview
69.57 Plainview captured
69.57 Convoy8 leaving Lubbock and moving to Abernathy 51.0 miles away.
69.92 Convoy5 started a 4.9 hour delay in transit at Houston
69.93 Convoy3 started a 4.1 hour delay in transit at Houston
70.33 Convoy1 started a 4.3 hour delay in transit at Houston
72.87 Convoy2 started a 4.7 hour delay in transit at Houston
72.97 Convoy8 arrived at Abernathy
72.97 Convoy8 started a 4.7 hour delay in transit at Abernathy
74.07 Convoy3 started a 4.1 hour delay in transit at Houston
74.62 Convoy1 started a 4.7 hour delay in transit at Houston
74.78 Convoy5 started a 4.7 hour delay in transit at Houston
77.59 Convoy2 started a 2.8 hour delay in transit at Houston

77.62 Convoy8 leaving Abernathy and moving to Plainview 51.0 miles away.
78.12 Convoy3 started a 4.5 hour delay in transit at Houston
79.33 Convoy1 started a 5.2 hour delay in transit at Houston
79.51 Convoy5 started a 4.2 hour delay in transit at Houston
80.39 Convoy2 started a 4.6 hour delay in transit at Houston
81.02 Convoy8 arrived at Plainview
82.60 Convoy3 started a 3.1 hour delay in transit at Houston
83.70 Convoy5 started a 2.7 hour delay in transit at Houston
84.57 Convoy1 started a 3.2 hour delay in transit at Houston
85.01 Convoy2 started a 3.5 hour delay in transit at Houston
85.72 Convoy3 started a 4.0 hour delay in transit at Houston
86.39 Convoy5 started a 4.2 hour delay in transit at Houston
87.73 Convoy1 started a 3.4 hour delay in transit at Houston
88.47 Convoy2 started a 4.8 hour delay in transit at Houston
89.69 Convoy3 started a 3.3 hour delay in transit at Houston
90.57 Convoy5 started a 3.3 hour delay in transit at Houston
91.14 Convoy1 started a 5.3 hour delay in transit at Houston
92.96 Convoy3 started a 5.6 hour delay in transit at Houston
93.24 Convoy2 started a 4.4 hour delay in transit at Houston
93.86 Convoy5 started a 2.6 hour delay in transit at Houston
96.42 Convoy1 started a 5.6 hour delay in transit at Houston
96.43 Convoy5 started a 3.8 hour delay in transit at Houston
97.65 Convoy2 started a 4.7 hour delay in transit at Houston
98.58 Convoy3 started a 4.6 hour delay in transit at Houston
100.22 Convoy5 started a 2.8 hour delay in transit at Houston
101.99 Convoy1 started a 5.0 hour delay in transit at Houston
102.36 Convoy2 started a 4.4 hour delay in transit at Houston
102.52 Houston's road facility repaired.
102.99 Convoy5 leaving Houston and moving to Abilene191.0 miles away.
103.23 Convoy3 leaving Houston and moving to Abilene191.0 miles away.
106.73 Convoy2 leaving Houston and moving to Abilene191.0 miles away.
107.01 Convoy1 leaving Houston and moving to Abilene191.0 miles away.
122.09 Convoy5 arrived at Abilene
122.09 Convoy5 started a 4.5 hour delay in transit at Abilene
122.33 Convoy3 arrived at Abilene
122.33 Convoy3 started a 4.0 hour delay in transit at Abilene
125.83 Convoy2 arrived at Abilene
125.83 Convoy2 started a 3.5 hour delay in transit at Abilene
126.12 Convoy1 arrived at Abilene
126.12 Convoy1 started a 3.5 hour delay in transit at Abilene
126.30 Convoy3 leaving Abilene and moving to Sweetwater 40.0 miles away.
126.58 Convoy5 leaving Abilene and moving to Sweetwater 40.0 miles away.

129.35 Convoy2 leaving Abilene and moving to Sweetwater 40.0 miles away.
129.59 Convoy1 leaving Abilene and moving to Sweetwater 40.0 miles away.
130.30 Convoy3 arrived at Sweetwater
130.30 Convoy3 started a 1.3 hour delay in transit at Sweetwater
130.58 Convoy5 arrived at Sweetwater
130.58 Convoy5 started a 3.8 hour delay in transit at Sweetwater
131.61 Convoy3 leaving Sweetwater and moving to Lubbock 51.0 miles away.
133.35 Convoy2 arrived at Sweetwater
133.35 Convoy2 started a 2.8 hour delay in transit at Sweetwater
133.59 Convoy1 arrived at Sweetwater
133.59 Convoy1 started a 4.5 hour delay in transit at Sweetwater
134.39 Convoy5 leaving Sweetwater and moving to Lubbock 51.0 miles away.
135.01 Convoy3 arrived at Lubbock
135.01 Convoy3 started a 3.4 hour delay in transit at Lubbock
136.10 Convoy2 leaving Sweetwater and moving to Lubbock 51.0 miles away.
137.79 Convoy5 arrived at Lubbock
137.79 Convoy5 started a 3.6 hour delay in transit at Lubbock
138.13 Convoy1 leaving Sweetwater and moving to Lubbock 51.0 miles away.
138.39 Convoy3 leaving Lubbock and moving to Abernathy 51.0 miles away.
139.50 Convoy2 arrived at Lubbock
139.50 Convoy2 started a 4.5 hour delay in transit at Lubbock
141.39 Convoy5 leaving Lubbock and moving to Abernathy 51.0 miles away.
141.53 Convoy1 arrived at Lubbock
141.53 Convoy1 started a 5.1 hour delay in transit at Lubbock
141.79 Convoy3 arrived at Abernathy
141.79 Convoy3 started a 3.6 hour delay in transit at Abernathy
144.00 Convoy2 leaving Lubbock and moving to Abernathy 51.0 miles away.
144.79 Convoy5 arrived at Abernathy
144.79 Convoy5 started a 2.7 hour delay in transit at Abernathy
145.44 Convoy3 leaving Abernathy and moving to Plainview 51.0 miles away.
146.63 Convoy1 leaving Lubbock and moving to Abernathy 51.0 miles away.
147.40 Convoy2 arrived at Abernathy
147.40 Convoy2 started a 2.9 hour delay in transit at Abernathy
147.47 Convoy5 leaving Abernathy and moving to Plainview 51.0 miles away.
148.84 Convoy3 arrived at Plainview
150.02 Convoy1 arrived at Abernathy
150.02 Convoy1 started a 4.7 hour delay in transit at Abernathy

150.35 Convoy2 leaving Abernathy and moving to Plainview 51.0 miles away.
150.87 Convoy5 arrived at Plainview
153.75 Convoy2 arrived at Plainview
154.77 Convoy1 leaving Abernathy and moving to Plainview 51.0 miles away.
158.17 Convoy1 arrived at Plainview
Closing the War Diary

Notice that the effects of interdiction are seen by the convoys backing up in Houston between 14.77 and 102.52 hours. The materiel that is stuck in Houston can be identified using the Supply Diary.

2. SUPPLY DIARY

Although not found in this example, many Supply Diaries will list "Manna" as having filled an order for the FLB at Houston. This indicates materiel that has flowed into theater.

Supply Diary
19.10 IDiv consumed 6262 of MoGas. Onhand: 5738.
19.10 Houston rcvd req for 6262 MoGas
19.10 Houston has filled an order for 6262 of MoGas
19.10 Convoy1 formed for IDiv using 8 truck
24.00 IDiv consumed 39974 of CRAT. Onhand: 60026.
24.00 Abilene rcvd req for 39974 CRAT
24.00 Abilene must backorder 29974 CRAT
24.00 Abilene has filled an order for 10000 of CRAT
24.00 IDiv received 10000 CRAT from Abilene. Now onhand: 70026.
24.00 Houston rcvd req for 29974 CRAT
24.00 Houston has filled an order for 29974 of CRAT
24.00 Convoy2 formed for IDiv using 29 truck
44.27 Abilene rcvd req for 24806 CRAT
44.27 Abilene must backorder 24806 CRAT
44.27 Houston rcvd req for 24806 CRAT
44.27 Houston has filled an order for 24806 of CRAT
44.27 Convoy3 formed for IDiv using 24 truck
46.63 IDiv consumed 1191 of MoGas. Onhand: 4547.
46.63 Abilene rcvd req for 1191 MoGas
46.63 Abilene has filled an order for 1191 of MoGas
46.63 Convoy4 formed for IDiv using 1 truck
48.00 IDiv consumed 41507 of CRAT. Onhand: 28519.
48.00 Abilene rcvd req for 41507 CRAT

48.00 Abilene must backorder 41507 CRAT
48.00 Houston rcvd req for 41507 CRAT
48.00 Houston has filled an order for 41507 of CRAT
48.00 Convoy5 formed for IDiv using 41 truck
49.13 IDiv received 1191 MoGas from Convoy4. Now onhand: 5738.
51.67 IDiv consumed 1639 of MoGas. Onhand: 4099.
51.67 Abilene rcvd req for 1639 MoGas
51.67 Abilene has filled an order for 1639 of MoGas
51.67 Convoy6 formed for IDiv using 2 truck
62.07 IDiv received 1639 MoGas from Convoy6. Now onhand: 5738.
64.62 IDiv consumed 1695 of MoGas. Onhand: 4043.
64.62 Lubbock rcvd req for 1695 MoGas
64.62 Lubbock has filled an order for 1695 of MoGas
64.62 Convoy7 formed for IDiv using 2 truck
67.02 IDiv received 1695 MoGas from Convoy7. Now onhand: 5738.
69.57 IDiv consumed 1656 of MoGas. Onhand: 4082.
69.57 Lubbock rcvd req for 1656 MoGas
69.57 Lubbock has filled an order for 1656 of MoGas
69.57 Convoy8 formed for IDiv using 2 truck
Closing Supply Diary

APPENDIX D. THE DATABASES

This Appendix contains all of the various databases used by the code along with explanatory notes. The databases are printed in New Courier, a fixed pitch font, to show precisely how they are listed. The code has a certain resiliency about how sloppy the data may be listed, but not much. FileManager.FileTracker.ParseChar shows the different delimiters it can recognize: tab spaces, commas, colons, and semicolons. Periods may not be used since they denote real numbers.

In general, the code expects to find data immediately following a [Field Name] listing and will read the data until it finds the next [Field Name]. A few other fields will use just the field name without brackets and use "end." to denote the end of the field. Since different processes in the program may need different fields from different files, or multiple fields from one single file, the fields themselves are not generally in any sequential order. When a field is needed, a FileTracker opens the appropriate file and searches until it finds the data field heading it seeks. However, the program does expect the listings within a field to be in orders listed here.

Although the tabulated data are separated by tab spaces, the program recognizes spaces, commas, semicolons, tab spaces, and period delimiters. The coding for the delimiter recognition is in FileManger.FileTracker.ParseChar.

The databases give the program a great deal of flexibility by allowing different scenarios to be run by changing a few lines in the appropriate database. Recompilation of the program is therefore unnecessary.

A. FileManager DATABASES

The FileManager object FileTracker uses two files constantly: FMScratchpad and TypeID.

1. FILE NAME FMScratchpad

A FileManger.FileTracker object depends upon FMScratchpad to operate. FMScratchpad is hardwired into a FileTracker's RootSource field by ObjInit and lists all of the file paths used in the program.

For example, suppose a method needs to change a TerrainType to a string. Since the FileTracker is working with a user enumerated type, it opens

FMScratchpad, looks for "UserTypes", and finds that they are listed in "InputFiles/TypeID".

```
FileManager Scratchpad

Input directory:  InputFiles/
Output directory: OutputFiles/

Data Input files
Agressor: InputFiles/Agressor
Defender: InputFiles/Defender
Map: InputFiles/NetworkData
WeaponsData: InputFiles/WeaponsData
Movement: InputFiles/ForceData
UserTypes: InputFiles/TypeID
LogPlanFactors: InputFiles/LogisticsPlanningFactors
DepotList: InputFiles/DepotList
IMTransport: InputFiles/IMTransportAssignments
RefereeInitialization: InputFile/RefereeStandingOrders

Data output files:
MapDump: OutputFiles/MapStructure
LPFODump: OutputFiles/LPFODump

WarDiary: OutputFiles/WarDiary
SupplyDiary: OutputFiles/SplyDiary
```

2. FILE NAME TypeID

TypeID lists all of the user enumerated types as they are found in the various definition modules. It is absolutely essential that these listings match exactly in spelling and ordinal the definition listing or errors will result. Comma delimiters are also required, and the line headers must match the spelling of the enumerated type.

```
TypeID
TerrainType: plain, hilly, mountainous, marshy, desert
WeaponType: MBT, INF, CAS, Arty
SplyClassType: subsistence, super, POL, ammo, major
ModeType:  air, rail, road, sea, JLOTS, IPDS
MovingObjType: truck, train, C130, ship, ELCAS, pipeline opforce,
      combat, engineer
```

B. MovingObj TERRAIN MOVEMENT DATABASE

```
Force Data
Terrain Movement Rates
```

	plain	hilly	mountainous	marshy	desert
combat:	20	10	5	1	2
opforce:	20	15	1	3	8
engineer:	15	12	5	1	2
truck:	15	10	5	1	2
C130:	250	250	250	250	250

```
END TERRAIN
```

C. FORCE AND DEPOT SYSTEM FILES

FileTracker uses three files, Aggressor, Defender, and DepotList, to tell the model run what files to use for Blue forces, Red forces, and Depots.

1. MovingObjType FILES

`Aggressor` and `Defender` tell the RefereeObj what files to use for Blue and Red Force objects. A template is shown below. Each unit in the Force object has a line listing. The file name should be the name of the unit.

```
"FileName" MovingObjType
```

2. DepotList FILES

The `DepotList` tells the RefereeObj which cities will have a Depot. Simply, the file lists each site that has a depot on its own line. The listing must match the spelling entered in the network database, and the very first entry is assumed to be the forward logistics base.

D. UnitType DATABASES

UnitType Objects use the format shown for the Blue and Red units. Both types need the Unit, Weapons, and Mission fields, although Red units cannot use the LiftMOType and LiftPerPerson entries under Unit Data. Only the Blue units need the Unit Load Out field. The Unit Load Out shows what a Logistics1.LoadListObj looks like.

As noted in the Weapons Data field, the unit's weapons systems are columnar and the opposition systems are by row. While backwards from most listings of this type, this approach simplified data entry in this case.

Originally, military (meter) grid system was intended for use. However, since most theaters cannot fit onto a single map and the program cannot process alphanumeric grid designators, the unit of measure changed to the mile. The grids listed, then, are based on Cartesian coordinate system in the first quadrant only.

1. BLUE FORCES

File name: IDiv

```
[Unit Data]
Name:IDiv
```

```
Number: 20000
Location: Houston
LiftPerPerson: 0.04
LiftMOType: truck
Grids:08911235

[Weapons Data]
Note:  Columns represent this unit's data.  Rows are opposition data

Force Breakpoint: 4
Weapons Types:          MBT     INF     CAS     Arty
Weapons Load:           256     17000   72      267
Weapons Breakpoint:     0.75    0.8     0.9     0.8


Psi: xx
        MBT             0.5     0.25    0.25    0.25
        INF             0.25    0.75    0.25    0.25
        CAS             0.0     0.0     0.25    0.25
        Arty            0.25    0.0     0.25    0.25

AmmoType: xx
        MBT             HE-1    LAAW    HELLFIR HE-2
        INF             PD-1    NATO    BOMB    PD-2
        CAS             None    None    AIM9    PD-2
        Arty            PD-1    None    HELLFIR PD-2

[Unit Load Out]
ULO:            subs    super   POL     Ammo    Major
Commodity:      CRAT    NoFill  JP5     LAAW    truck
Onhand:         100000          50000   1000    800
Cap:            100000          700     1000    800
Reorder:        0.9             0.75    0.9     0.9

Commodity:      NoFill  NoFill  MoGas   BOMB    MBT
Onhand:                         12000   6000    256
Cap:                            12000   6000    256
Reorder:                        0.6     0.9     1.0

Commodity:      NoFill  NoFill  NoFill  HELLFIR INF
Onhand:                                 400     17000
Cap:                                    400     17000
Reorder:                                0.9     1.0

Commodity:      NoFill  NoFill  NoFill  AIM9    CAS
Onhand:                                 50      72
Cap:                                    50      72
Reorder:                                0.9     1.0

Commodity:      NoFill  NoFill  NoFill  NATO    Arty
Onhand:                                 2000000 267
Cap:                                    2000000 267
Reorder:                                0.9     1.0

Commodity:      NoFill  NoFill  NoFill  HE-1    NoFill
Onhand:                                 400
Cap:                                    400
Reorder:                                0.9
```

```
Commodity:      NoFill  NoFill  NoFill  PD-1    NoFill
Onhand:                                 50
Cap:                                    50
Reorder:                                0.9

Commodity:      NoFill  NoFill  NoFill  HE-2    NoFill
Onhand:                                 2000000
Cap:                                    2000000
Reorder:                                0.9

Commodity:      NoFill  NoFill  NoFill  PD-2    NoFill
Onhand:                                 400
Cap:                                    400
Reorder:                                0.9

Mission:
Houston, US-36
Abilene, I-20
Sweetwater, US-86
Lubbock, I-25
Abernathy, I-25
Plainview, STOP
end.
```

2. RED FORCES

```
File name: 789thMech

Name:  789thMech
Number: 15000
Location:  Plainview
Grids:  00050035

[Weapons Data]
Note:  Columns represent this unit's data.  Rows are opposition data

Force Breakpoint: 4
Weapons Types:          MBT     INF     CAS     Arty
Weapons Load:           200     15000   50      267
Weapons Breakpoint:     0.75    0.8     0.9     0.8


Psi: xx
        MBT             0.5     0.25    0.25    0.25
        INF             0.25    0.75    0.25    0.25
        CAS             0.0     0.0     0.25    0.25
        Arty            0.25    0.0     0.25    0.25

Mission:
Plainview, I-25
Abernathy, I-25
Lubbock, US-86
Sweetwater, I-20
Abilene, US-36
Houston, STOP
end.
```

3. COMBAT MODEL INFORMATION

These databases show the data used in the combat model section. Unlike the listing for the UnitTypes, opposition data is columnar.

```
WeaponsData
{NOTE:  Subheadings PSSK and FIRETYPE need the "xx"' s
   after or program crashes in FindField, Isloate ":"
   PSSK and FIRETYPE are read by row against opposer column}


[Red Data]
WeaponType     Rounds/hr     Footprint-sqft        Crew Size
MBT              80              3000                   5
INF              100             400                    1
CAS              75              1000000                1
ARTY             120             10000                  8

Pssk: xx
         MBT      INF      CAS      Arty
MBT:     0.0023   0.0001   0.0001   0.0023
INF:     0.0001   0.0023   0.0001   0.0001
CAS:     0.0030   0.0015   0.0010   0.0045
Arty:    0.0034   0.0024   0.0001   0.0901

FireType: xx
         MBT      INF      CAS      Arty
MBT:     Aimed    Aimed    Aimed    Aimed
INF:     Aimed    Aimed    Aimed    Aimed
CAS:     Aimed    Aimed    Aimed    Aimed
Arty:    Aimed    Aimed    Aimed    Aimed

[Blue Data]
WeaponType     Rounds/hr     Footprint-sqft        Crew Size
MBT              80              3100                   5
INF              120             415                    1
CAS              67              1000234                1
Arty             89              10012                  8

Pssk: xx
         MBT      INF      CAS      Arty
MBT:     0.0023   0.0001   0.0001   0.0023
INF:     0.0001   0.0023   0.0001   0.0001
CAS:     0.0030   0.0015   0.0010   0.0045
Arty:    0.0034   0.0024   0.0001   0.0901

FireType: xx
         MBT      INF      CAS      Arty
MBT:     Aimed    Aimed    Aimed    Aimed
INF:     Aimed    Aimed    Aimed    Aimed
CAS:     Area     Area     Aimed    Aimed
Arty:    Area     Area     Area     Area
```

E. DEPOT DATABASES

The DepotList tells the Referee which sites will have a depot and what the name of the file is for that depot: depot file names are the site names with "Depot". The filename for the forward logistics base at Houston is "HoustonDepot". Although intermediate depots need not have a listing for every item used in the theater, the forward logistics base must, even if the item is not carried by the FLB. If the FLB receives a request for an item it does not list, the program will halt and notify the user. Note that the supply listing is a LoadListObj.

```
The Depot at Houston.
ULO:            sub     super   POL     ammo    major
Commodity:      MRE     Stuff   MoGas   NATO    truck
Onhand:         1000    23      700000  8000000 1000
Cap:            2000    23      700000  8000000 1000
Reorder:        0.1     0.1     0.1     0.7     0.1

Commodity:      CRAT    Mores   JP5     LAAW    C130
Onhand:         500000  234     50000   100     3
Cap:            500000  500     50000   700     3
Reorder:        0.1     0.1     0.1     0.1     0.1

Commodity:      NoFill  Bridge  NoFill  BOMB    MBT
Onhand:                 3               10      50
Cap:                    3               6000    50
Reorder:                0.0             0.1     1.0

Commodity:      NoFill  bldg    NoFill  HELLFIR INF
Onhand:                 10              400     1000
Cap:                    20              400     1000
Reorder:                0.5             0.1     1.0

Commodity:      NoFill  NoFill  NoFill  AIM9    CAS
Onhand:                                 45      15
Cap:                                    50      15
Reorder:                                0.1     1.0

Commodity:      NoFill  NoFill  NoFill  LGB     Arty
Onhand:                                 600     4
Cap:                                    700     10
Reorder:                                0.1     1.0

Commodity:      NoFill  NoFill  NoFill  HE-1    NoFill
Onhand:                                 400
Cap:                                    400
Reorder:                                0.9

Commodity:      NoFill  NoFill  NoFill  PD-1    NoFill
Onhand:                                 50
Cap:                                    50
Reorder:                                0.9
```

```
Commodity:      NoFill  NoFill  NoFill  HE-2    NoFill
Onhand:                                 2000000
Cap:                                    2000000
Reorder:                                0.9

Commodity:      NoFill  NoFill  NoFill  PD-2    NoFill
Onhand:                                 400
Cap:                                    400
Reorder:                                0.9
```

F. MAP STRUCTURE

The file path for the network data is given in FMScratchpad. Each listing in the file is a terminal with its forward star of arcs. MapStructure.CreateMap uses the GeoLoc field to attach the terminal to a site. If a site with a terminal's GeoLoc field does not exist, one will be created. A site may have a single terminal, such as a bridge or tunnel listing, or many, as a city might. Since each terminal is read individually, no specific order is necessary. On the other hand, it is essential that each site's spelling is used consistently throughout since the name is used as a unique identifier. A misspelled name can cause a site to be created with unintended consequences when arcs fail to go where they are imagined. Finally, each arc is directed. If a two way rail arc exists between Abilene and Houston, it must be listed as an arc from Abilene to Houston, and as an arc from Houston to Abilene.

```
NetworkData
GeoLoc:  Abernathy
Grids:  00040030
Desc:  I-25
Mode:  road
Cap:  1400 trucks/day
Star:
Lubbock     plain   1400 trucks/day
Plainview   plain   1400 trucks/day
end.

GeoLoc:  Lubbock
Grids:  00050025
Desc:  Santa Fe yard
Mode:  rail
Cap:  350 cars/day
Star:
Abernathy   plain   350 cars/day
Sweetwater  plain   350 cars/day
Abilene     plain   350 cars/day
end.

GeoLoc:  Houston
Grids:  00120001
Desc:  Rail Yard
Mode:  rail
Cap:  700 cars/day
Star:
```

```
Sweetwater  hilly 200 cars/day
Abilene     hilly 350 cars/day
end.

GeoLoc: Lubbock
Grids:  00050025
Desc:  US-86
Mode:  road
Cap:  1000 trucks/day
Star:
Sweetwater   plain  1000 trucks/day
end.

GeoLoc:  Sweetwater
Grids:  00060020
Desc:  US-86
Mode:  road
Cap:  1000 trucks/day
Star:
Lubbock   plain  1000 trucks/day
end.

GeoLoc:  Sweetwater
Grids: 00060020
Desc:  I-20
Mode:  road
Cap:  1800 trucks/day
Star:
Abilene      hilly 1800 trucks/day
end.

GeoLoc:  Abilene
Grids: 00100020
Desc:  US-36
Mode:  road
Cap:  400 trucks/day
Star:
Houston  hilly  400 trucks/day
end.

GeoLoc: Abilene
Grids: 00100020
Desc:  I-20
Mode:  road
Cap:  1800 trucks/day
Star:
Sweetwater  hilly  1800 trucks/day
end.

GeoLoc:  Houston
Grids:  00120001
Desc:  US-36
Mode:  road
Cap:  400 trucks/day
Star:
Abilene  hilly  1800 trucks/day
end.

GeoLoc: Houston
```

```
Grids: 00120001
Desc:  Port of Houston
Mode:  sea
Cap:  700 containers/day
Star:
SuperSeaNode  plain  0 ships/day
end.

GeoLoc: Sweetwater
Grids: 00060020
Desc:  Rail yard
Mode:  rail
Cap:  350 cars/day
Star:
Lubbock  plain   350 cars/day
Abilene  hilly   350 cars/day
Houston  hilly  200 cars/day
end.

GeoLoc: Abernathy
Grids: 00040030
Desc:  Rail yard
Mode:  rail
Cap:  300 cars/day
Star:
Lubbock     plain  300 cars/day
Plainview   plain  300 cars/day
end.

GeoLoc: Plainview
Grids: 00050035
Desc:  I-25
Mode:  road
Cap:  1500 trucks/day
Star:
Abernathy  plain   1500 trucks/day
end.

GeoLoc: Plainview
Grids: 00050035
Desc:  siding
Mode:  rail
Cap:  300 cars/day
Star:
Abernathy   plain  1500 trucks/day
end.

GeoLoc: Lubbock
Grids: 00050025
Desc:  I-25
Mode:  road
Cap:  1400 trucks/day
Star:
Abernathy   plain   1500 trucks/day
end.

GeoLoc: Abilene
Grids: 00040030
Desc:  Rail Yard
```

```
Mode:  rail
Cap:   350 cars/day
Star:
Lubbock       plain 350 cars/day
Sweetwater    hilly 350 cars/day
Houston       hilly 350 cars/day
end.
```

G. LOGISTICS PLANNING FACTORS

The logistics planning factors are shown below. Each planning factor must be listed under its SplyClassType. If the program cannot find the planning factor it seeks, it notifies the user and halts. Some items may be both a commodity and a user. For instance, trucks are used by MovingObjTypes combat and engineer, but use MoGas themselves.

```
Logistics Planning Factors.
[subsistence]
NounName: MRE
User: combat
HighUseage: 3
MedUseage: 2
LowUseage:1
Weight:1
CUFT:0.2

NounName: CRAT
User: combat
HighUseage: 3
MedUseage:2
LowUseage:1
Weight:1
CUFT:0.5

NounName: CRAT
User: engineer
HighUseage: 3
MedUseage: 2
LowUseage: 1
Weight: 1
CUFT:0.5

NounName: Water
User: combat
HighUseage: 25
MedUseage: 15
LowUseage: 5
Weight: 8
CUFT: 0.66
[super]
NounName: Stuff
User: combat
HighUseage: 5
MedUseage: 4
LowUseage:1
Weight:23
CUFT:1
```

```
NounName: Bridge
User: engineer
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight 10000
CUFT: 500

NounName: bldg
User: engineer
HighUseage 2
MedUseage 1.5
LowUseage 1
Weight 2000
CUFT: 10

NounName: Mores
User: combat
HighUseage:5
MedUseage:3
LowUseage:2
Weight:2
CUFT:2

[POL]
NounName: MoGas
User: combat
HighUseage: 0.05
MedUseage: 0.04
LowUseage: 0.03
Weight: 7
CUFT: 0.66

NounName: MoGas
User: truck
HighUseage: 0.05
MedUseage:  0.04
LowUseage: 0.033
Weight: 7
CUFT: 0.66

NounName: JP5
User: C130
HighUseage: 400
MedUseage:  350
LowUseage:  200
Weight: 7
CUFT:0.66

[ammo]
NounName: Dragon
User: combat
HighUseage: 3
MedUseage:2
LowUseage:1
Weight:100
CUFT:10
```

```
NounName: LAAW
User: combat
HighUseage: 3
MedUseage: 2
LowUseage:1
Weight: 100
CUFT: 10

NounName: BOMB
User: combat
HighUseage: 8
MedUseage: 6
LowUseage: 4
Weight: 500
CUFT: 12

NounName: HELLFIR
User: combat
HighUseage: 8
MedUseage: 6
LowUseage: 4
Weight: 500
CUFT: 12

NounName: AIM9
User: combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 500
CUFT: 12

NounName:  NATO
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 0.04
CUFT:  0.001

NounName:  HE-1
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 35
CUFT:  1

NounName:  PD-1
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 35
CUFT:  1

NounName:  HE-2
User:  combat
HighUseage: 1
```

```
MedUseage: 1
LowUseage: 1
Weight: 35
CUFT:  1

NounName:  PD-2
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 35
CUFT:  1

[major]
NounName:  truck
User:  truck
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 5000
CUFT:  500

NounName:  MBT
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 40000
CUFT:  4000

NounName:  INF
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 200
CUFT:  24

NounName:  CAS
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 1
CUFT:  1

NounName:  Arty
User:  combat
HighUseage: 1
MedUseage: 1
LowUseage: 1
Weight: 4000
CUFT:  1000
```

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16. Office of the Secretary of Defense — 2
Program Analysis and Evaluation, JWARS Office
Attn: LCDR Jeffrey Cares
Crystal Square Four, Suite 100
1745 Jefferson Davis Highway
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17. Lt. Joseph Huffaker — 1
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